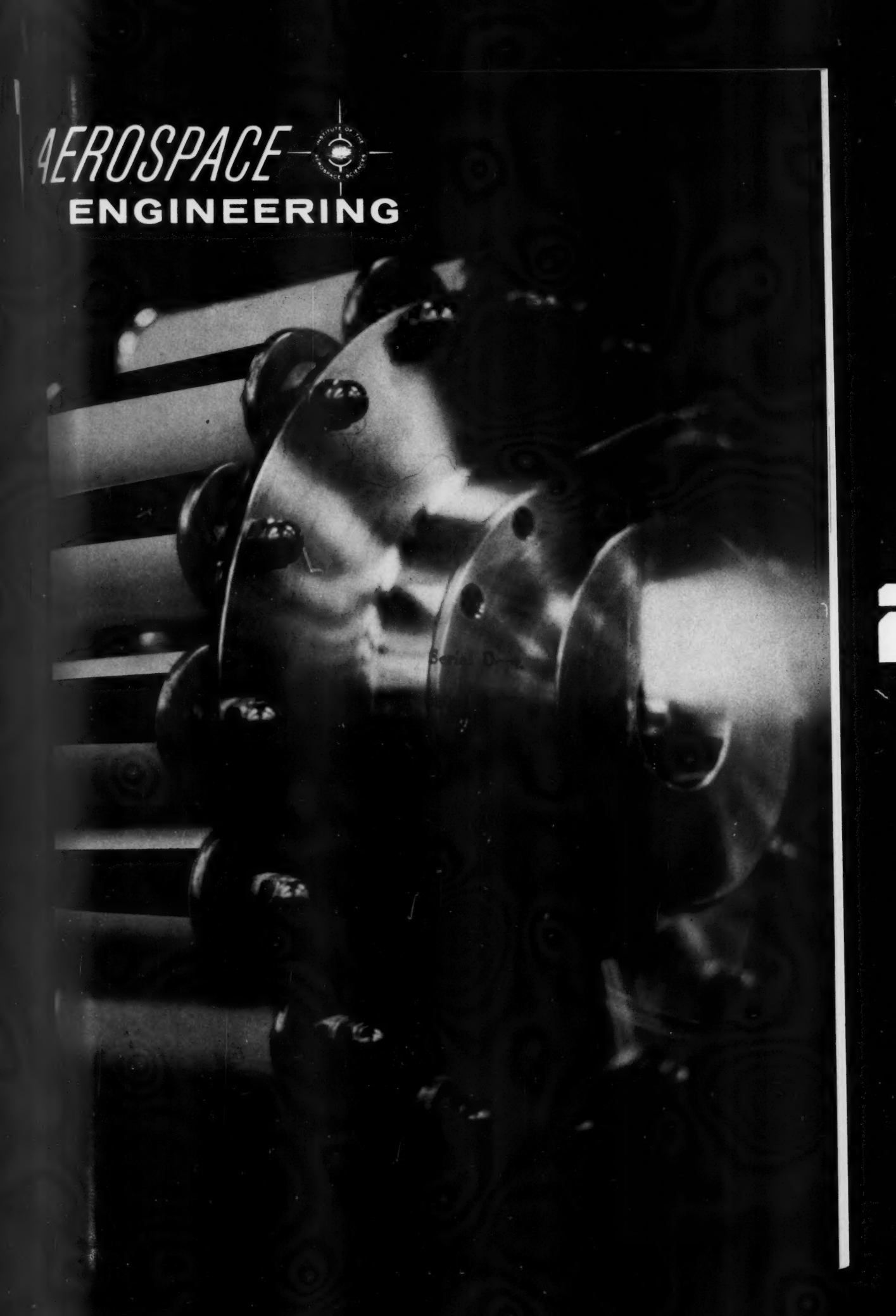
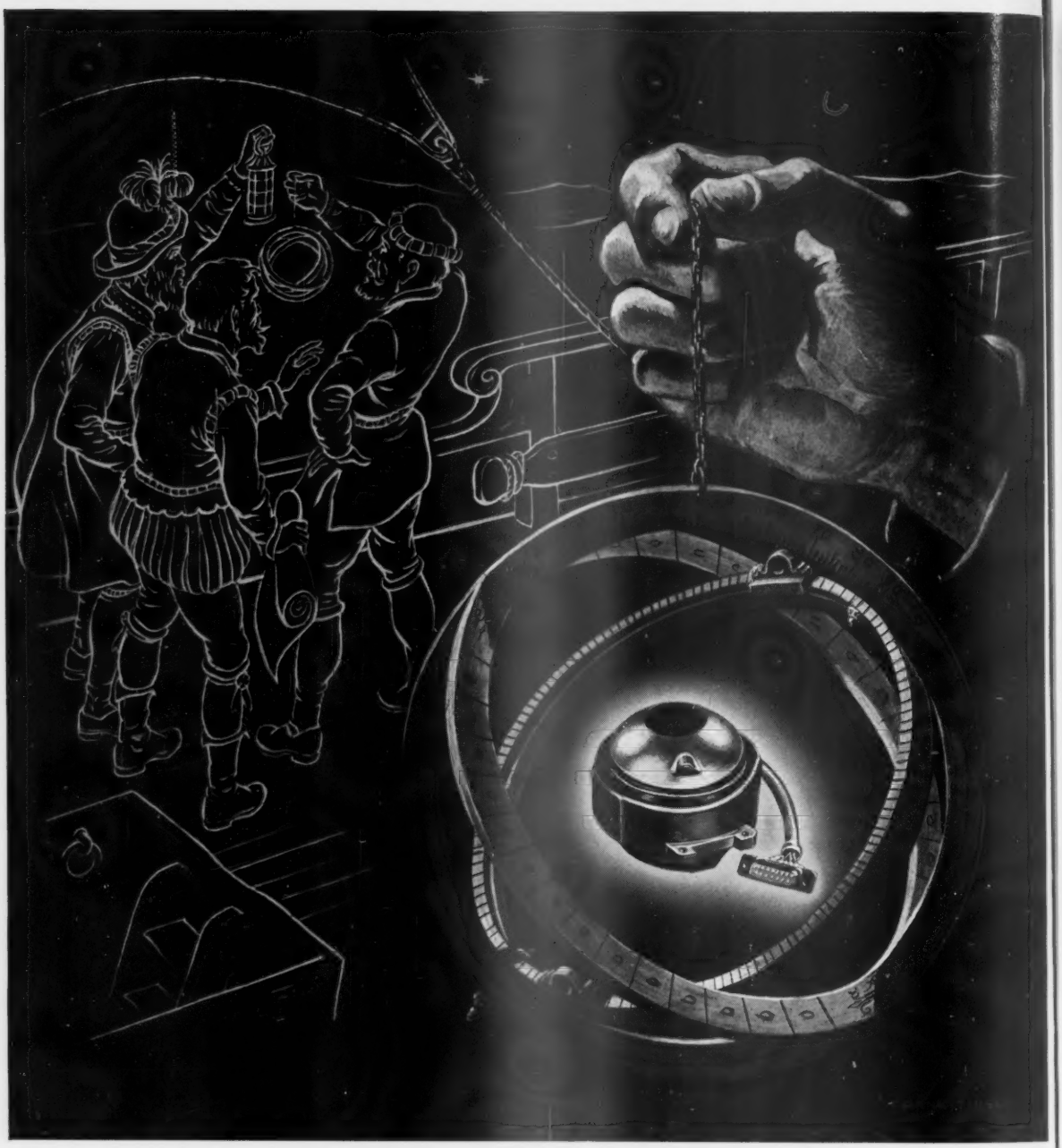
# AEROSPACE ENGINEERING





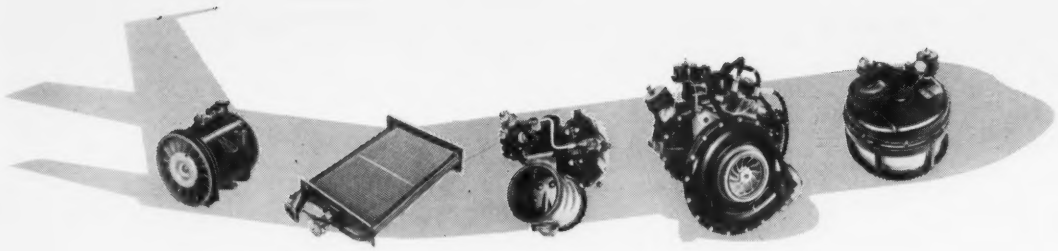
# *Navigation by sure eye and steady hand*

Ferdinand Magellan successfully steered his ships around the world with the aid of an "astronomical ring" . . . one of the navigational wonders of his age. Hung from the steady hand of a sure-eyed seaman, readings were taken by sighting through the rings. Set for the month and day of the week, this ingenious device employed the sun's declination to first determine latitude, then the hour and finally the meridional point of the ship's position.

Today, the "sure eye and steady hand" of Arma's inertial guidance system solves the intricate problems posed by navigating in space . . . keeps space vehicles on course by sensing the most minute changes from programmed speed and direction. And, despite its precise capabilities, the sensing gyro of the guidance system is small enough to be completely encompassed within Magellan's unique brass rings.

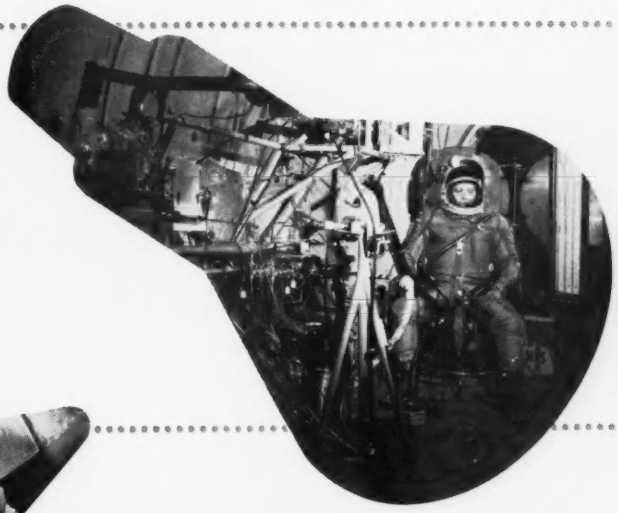
Arma, developer of the all inertial Atlas guidance system, airborne fire-control systems, weapons systems for all Navy submarines, and pioneer in space research programs, provides industry and the defense establishment with products and systems of top reliability and value. ARMA, Garden City, New York, a division of American Bosch Arma Corporation . . . the future is our business.

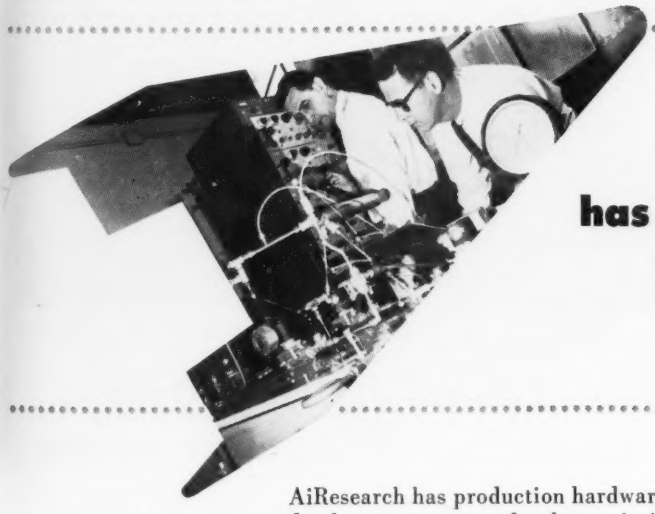
**AMERICAN BOSCH ARMA CORPORATION**



Only AiResearch has 2 million components in aircraft environmental systems*

**Only AiResearch has life support systems for America's astronauts**





**Only AiResearch has environmental systems <u>now</u> for tomorrow's spacecraft**

AiResearch has production hardware experience or has reached advanced stages in development contracts for these principal areas of a space environmental system: space radiators, glycol loops, supercritical cryogenic storage, atmospheric controls, fans, compressors and pumps.

The company's proven ability to produce all the components and integrate them into a complete environmental system reduces the problems of interface and assures the highest degree of optimization.

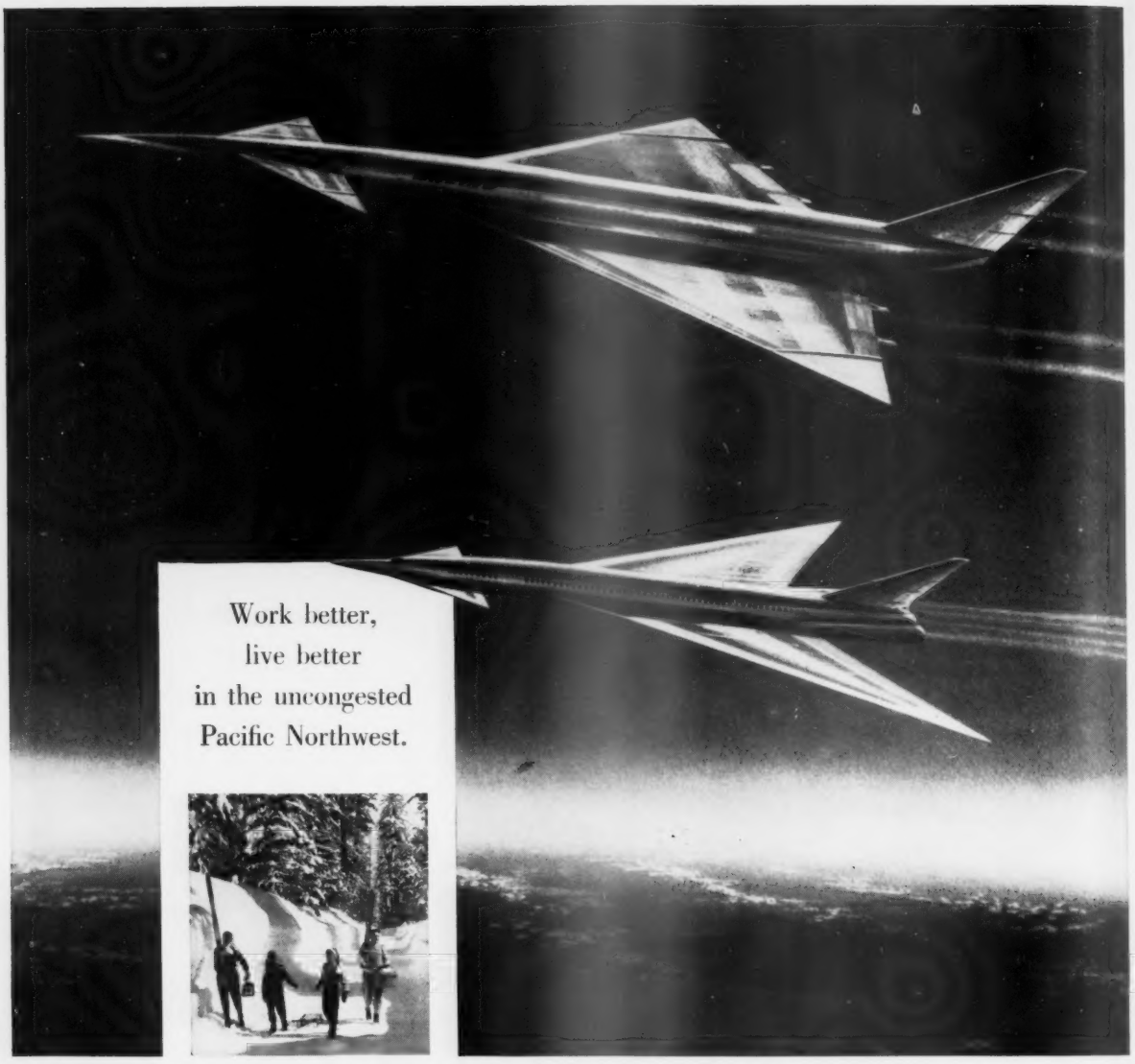
A new laboratory is now being added to present facilities specifically designed to test environmental control systems for advanced space missions.

**In world-wide service, with mean time between failure from 5000 to 40,000 hours on major high speed rotating machinery.*

GARRETT

**AIRESEARCH MANUFACTURING DIVISIONS** • *Los Angeles 45, California • Phoenix, Arizona*

*Systems and Components for:*
*Aircraft, Missile, Spacecraft, Electronic, Nuclear and Industrial Applications*




*Designs based on Boeing supersonic transport studies. Inset shows mountain ski area one hour from evergreen Seattle.*

# Advanced Boeing programs offer rewarding futures for

## STRUCTURAL, MECHANICAL AND AERONAUTICAL ENGINEERS

Design of supersonic skyliner of the future is one of many advanced projects under way at the Transport Division of Boeing. Other programs offering engineers scope and a chance to grow in professional stature are the new three-engine Boeing 727 jetliner and continuing programs in connection with the famous 707 and 720 jetliners.

Expanding Boeing programs have created openings for qualified structural, mechanical and aeronautical engineers in a wide range of activities in research, development, design, manufacturing and test. Although aircraft experience is desirable, training and assignments are available, on a selective basis, to graduate engineers in other fields who wish to apply their capabilities to aircraft projects.

At Boeing, world leader in multi-jet aircraft, you'll be backed by research facilities unequalled in the industry. And you'll be working in a dynamic career environment that's conducive to rapid advancement.

The Boeing Transport Division is located in the uncongested Pacific Northwest, noted for mild year-round climate, nationally famous recreational facilities, excellent schools and housing, and healthful outdoor Western living for the whole family.

**MAIL COUPON TODAY**

*Mr. Ivan Phillips, Transport Division, The Boeing Company, P.O. Box 707-BAW, Renton, Wash. The Boeing Company is an equal opportunity employer.*

NAME

ADDRESS CITY STATE

DEGREE(S) HELD

SCHOOL(S), YEAR GRADUATED

FIELD OF INTEREST YEARS EXPERIENCE

TRANSPORT DIVISION **BOEING**

Other Divisions: Aero-Space • Military Aircraft Systems • Vertol
Industrial Products • Also, Boeing Scientific Research Laboratories

"Written Exclusively By Engineers—For Engineers"

# AEROSPACE ENGINEERING

– Established 1934 –

VOLUME 20 / NUMBER 12

DECEMBER 1961

## Featured in this Issue


| | | |
|---|---|---|
| | 8 | Aerospace Technology as Seen by the Panels<br>Support—Lunar Support Equipment—The Time Is Now...<br>Gilbert Rolan<br>Space Physics—Environment for Manned Space Flight...<br>John C. Evvard |
| *Richard Hutton* | 10 | Naval Attack Aviation for Limited War • 1965–1975 |
| *George R. Gehrkens* | 12 | The Fleet Carrier Attack Problem in Limited War |
| *John E. Clark* | 14 | Problems of Antisubmarine Warfare |
| *W. Paul Thayer* | 16 | The Missile Threat—Future Anti-Air Warfare |
| *Donald W. Douglas, Jr.* | 18 | Rapid Sea-Wide Supply |
| *D. P. Germeraad* | 20 | Airborne With the Curtiss A-1 Replica |
| *Oskar Morgenstern* | 22 | A Political Economist Views the Navy/Industry Look at the Future |
| *William P. Kennedy* | 24 | Short-Haul Air Transportation |
| *J. H. Laub and H. D. McGinness* | 26 | Gas-Floated Spinning Spheres |
| *David A. Lieberman, Peter G. Fielding, and William J. Neff* | 28 | Control of Ground Effect Machines—Preliminary Analysis |
| *F. R. Shanley* | 30 | Tensile Instability (Necking) of Ductile Materials |
| *Departments* | 32 | Adventures in Engineering—<br>Twenty Times Better...Harry Weitz |
| | 33 | Letters to the Editor |
| | 64 | IAS Papers |
| | 80 | Sherman M. Fairchild Publication Fund Papers |
| | 81 | Index to Volume 20 |
| | 90 | IAS Special Publications and Papers |
| | 91 | Personnel Opportunities |
| | 91 | Reader Feedback |
| | 92 | Index to Advertisers |


EDITOR'S NOTE

December's AEROSPACE ENGINEERING has been created specifically to give readers unable to attend the classified IAS/Navy Naval Aviation Meeting (San Diego, Aug. 19–24) as much information presented there as possible. While the issue contains 11 full-length articles, the seven declassified contributions beginning on page 10 constitute this effort and, hopefully, might elicit reader reactions as to similar treatment of classified meetings in the future. Nonstaff help has been generous, but special thanks are due John W. Hopkins, AIAS, of General Dynamics/Convair, who was Program Chairman of the meeting, for obtaining transcripts.

## On our cover

A combination of color film and photographic technique provides some interesting hues around a pulsed plasma pinch engine being tested in the Plasma Propulsion Laboratory of Republic Aviation Corporation. Destined for use in space, the engine makes use of the self-induced electromagnetic pinch effect, set up by discharging a capacitor across two nozzle-shaped electrodes, wherein a radial pinch is converted to axial motion of ionized gas between the electrodes. The engine pictured is a model that may be well suited for use in a long-term, high-accuracy attitude control system. Republic is a Corporate Member of the IAS.

AEROSPACE
ENGINEERING
ESTABLISHED 1934

# EDITORIAL STAFF

*Publisher:* **Welman A. Shrader, AIAS**

*Editor:* **Allan Bernhardt, AIAS**

*Editorial Production Manager:* **Vehig S. Tavitian**

*Editorial Assistant:* **Helen S. Goldman**

*Associate Editor:* **Paul J. Burr, AFIAS**

*Technical Consultants:* **R. L. Bisplinghoff, FIAS**
**Abraham Hyatt, FIAS**

## AEROSPACE TECHNOLOGY PANELS

* Indicates Chairman

**Paul J. Burr, IAS Technical Services Director, Coordinator**

**Aerodynamics and Fluid Mechanics**
Lester Lees*
Seymour M. Bogdonoff
Dean R. Chapman
Antonio Ferri
Paul Germain
Wayland C. Griffith
Hans W. Liepmann
C. C. Lin
Henry T. Nagamatsu
W. R. Sears
John R. Sellars
R. T. Whitcomb
Hideo Yoshihara

**Aeroelasticity**
R. L. Bisplinghoff*
Y. C. Fung
I. E. Garrick
Martin Goland
Kurt H. Hohenemser
J. C. Houbolt
W. P. Jones
W. J. Mykytow
Robert F. Speaker

**Biomedical Sciences**
Don Flickinger*
W. Ross Adey
Capt. William Augerson, USA
Stuart Bondurant
A. Scott Crossfield
Cdr. J. H. Ebersole, USN
W. R. Lovelace, II
Bruce Pinc
Stanley N. Roscoe
*Foreign Correspondent,*
Hilding Bjurstedt

**Communication**
P. C. Sandretto*
K. C. Black
James M. Bridges
Harvard L. Hull
Leonard Jaffe
David S. Little
Lt. Cdr. M. M. Macomber
Paul Rosenberg
William J. Sen
Arnold Shostack
Teck A. Wilson

**Control and Guidance**
Robert N. Brown*
B. Paul Blasingame
S. F. Eyestone
C. E. Gallagher
Percy Halpert
B. J. O'Connor
Robert L. Roderick
S. F. Schmidt
O. Hugo Schuck
H. Philip Whitaker

**Energy Conversion**
David Altman*
Robert Bromberg
M. U. Clauser
J. Preston Layton
Frank Marble
G. H. Markstein
A. M. Rothrock
Milton M. Slawsky
Martin Summerfield
T. Y. Toong

**Flight Mechanics**
H. J. Kelley*
Malcolm J. Abzug
H. Julian Allen
A. E. Bryson, Jr.
T. N. Edelbaum
William C. House
George Leitmann
Bernard Maggin
Angelo Miele
John D. Nicolaides
Charles B. Westbrook

**Instrumentation**
Paul F. Bechberger*
J. M. Hungerford
Max A. Lowy
Walter McKay
M. David Prince
Charles P. Sonett
George I. Toumanoff
Ralph H. Tripp
William A. Wildhack

**Management**
Edward A. Ledeen*
Garrett C. Covington, Jr.
Maj. Gen. Marvin C. Demler, USAF
Richard G. Folsom
Joel M. Jacobson
Boyd C. Myers
Sidney M. Robbins
Lewis A. Rodert
John H. Sidebottom
R. C. Siebold
T. Paul Torda

**Meteorology**
Thomas F. Malone*
Robert D. Fletcher
Henry T. Harrison
Joseph Kaplan
Donald T. Perkins
Herbert Riehl
Morris Tepper
Clayton Van Thullenar
Harry Wexler

**Nuclear Applications**
J. Donald Rauth*
Jack L. Armstrong
Robert W. Bussard
H. M. Dieckamp
R. L. Duncan
Harold B. Finger
Donald J. Keirn
Frank E. Rom
Raymer E. Schreiber
D. Roy Shoults
T. B. Taylor

**Operations**
Richard V. Rhode*
Maj. Gen. Otis Benson, USAF (MC)
Ernest A. Cutrell
R. Adm. E. E. Fawkes, USN
Melvin N. Gough
Benjamin S. Kelsey
Franklin W. Kolk
Col. J. L. Marinelli, USA
W. E. Rhodes
M. B. Spaulding, Jr.
D. N. Yates

**Propulsion Systems**
Bruce T. Ludin*
Robert H. Boden
George W. Brady
David Cochran
Elliot Mitchell
Perry W. Pratt
C. C. Ross
John G. Wilder, Jr.
Maurice J. Zucrow

**Space Physics**
John C. Evvard*
Herbert Friedmann
Leo Goldberg
C. F. Hansen
Arthur Kantrowitz
Bruno Rossi
S. F. Singer
Leo Steg
Fred L. Whipple

**Structures and Materials**
Nicholas J. Hoff*
Samuel B. Batdorf
Bruno A. Boley
Pol Duwez
R. R. Heldenfels
Samuel Levy
George N. Mangurian
S. S. Manson
Nathan E. Promisel
Ernest E. Sechler

**Support**
Ernest G. Stout*
Albert D. Brown
Edward I. Brown
Col. Paul T. Cooper, USAF
P. J. Daniel
Paul Hartline
Donald R. Hill
Capt. N. D. Hodson, USN
Lt. Col. George L. Lovett
R. R. Malik
John McKenna
Gilbert Rolan
Richard A. Schmidt
William R. Owens

**Vehicle Design**
C. E. Pappas*
Adolph Burstein
C. H. Christenson
A. J. Eggers, Jr.
Robert Lichten
E. V. Marshall
Rene H. Miller
John R. Ragazzini
George S. Schairer
George S. Trimble, Jr.

**Aerospace Engineering** (established 1934) is published monthly by the Institute of the Aerospace Sciences, Inc., at 20th and Northampton Streets, Easton, Pa. Headquarters and Editorial Offices: 2 East 64th Street, New York 21, N. Y. (TEmpleton 8-3800). Western Office: 7660 Beverly Blvd., Los Angeles 36, Calif. Subscription rates: United States and possessions, 1 year, $5.00; single copies, $0.50. Foreign countries including Canada (American currency rates), 1 year, $6.00; single copies, $0.50. Second-class mail privileges authorized at Easton, Pa. This publication is authorized to be mailed at the special rates of postage prescribed by Section 132.122. Notices of change of address should be sent to the Circulation Department, Institute of the Aerospace Sciences, Inc., 2 East 64th Street, New York 21, N.Y., at least 30 days prior to actual change of address. © Copyright, 1961, by the Institute of the Aerospace Sciences, Inc. Statements and opinions expressed in *Aerospace Engineering* are to be understood as individual expressions and not those of the Institute.

*Business Manager and Advertising Production*

**John Phillips**

*Advertising Director*

**John R. Cockerell**
**116 So. Michigan Ave.**
**Chicago 3, Ill.**
**ANdover 3-6929**

*National Advertising Regional Offices*
**John Cockerell, Inc.**

**(Headquarters)**
**116 So. Michigan Ave.**
**Chicago 3, Ill.**
**ANdover 3-6929**

**3757 Wilshire Blvd.**
**Los Angeles 5, Calif.**
**DUnkirk 3-1135**

**380 Lexington Ave.**
**New York 17, N.Y.**
**OXford 7-9048**

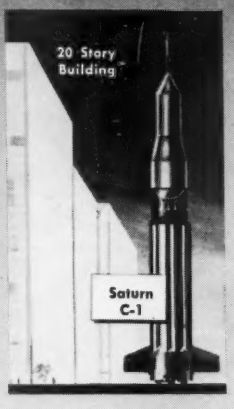
**1501 Euclid Ave.**
**Cleveland 15, Ohio**
**TOwer 1-8338**

**915 Olive Street**
**St. Louis 1, Mo.**
**GArfield 1-0907**

**141 N.E. Third**
**Miami 32, Fla.**
**FRanklin 1-9941**


AEROSPACE ENGINEERING welcomes contributions of full-length technical articles containing new and unpublished information, including manuscripts classified as technical notes, pertaining to all fields of interest in the Aerospace Sciences. (See headings of IAS Aerospace Technology Panels on opposite page.) Manuscripts in either category, which should be addressed to The Editor, Aerospace Engineering, 2 East 64th Street, New York 21, N.Y., are acknowledged on receipt. Editorial review—requiring from two to six weeks—is initiated with a promptness dependent upon conformance to standards discussed below. Authors are notified as soon as possible as to acceptance or rejection. To avoid delays and minimize correspondence, contributors are urged to supply the Editor with the original manuscript plus one or two legible (carbon or process) copies complete with clear copies of illustrations. Manuscripts should not exceed 17–20 pages (maximum of 5,000 words). Each should be typed (double-spaced) and every page must be typed with two-inch margins. For each illustration, deduct 350 words; for any tabular matter, deduct an equivalent number of words from text. Detailed instructions for preparation of manuscripts are published monthly on the inside back cover of the *Journal of the Aerospace Sciences*. *Aerospace Engineering* does not pay for contributions.


# K-Seals get the A-OK* in Saturn tests




Saturn's 8 engines develop 1.5 million pounds of thrust, enough to deliver over 5,000 pounds of instruments on the moon.

*** IN "MISSILE-ESE"—EVERYTHING WORKING PERFECTLY**

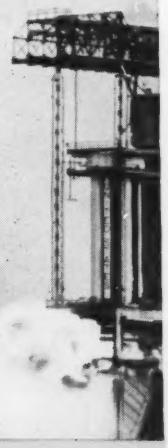
There's great activity and optimism at Huntsville where NASA's mighty Saturn C-1 is being readied for flight tests this year.

It is gratifying that the K-SEAL is "doing its job" on this vital project leading up to the development of a rocket powerful enough to send a 3-man Apollo Spaceship around the moon by 1965 or 1966. For the reliable K-SEAL, it's another "A—OK"...one for which we're justifiably proud.

**Write or wire for our new 38-page bound catalogue**... the most complete and comprehensive Metal Seal book in the industry. Gives sizes, specifications, test results, installation and ordering instructions, materials and finishes.

Covers: AND-10050 ports, Flange Type Connections, External Pressure Seals, Miniature Seals, and the new ASTRO/WEIGHT Fittings designed specifically for Missile Plumbing.

*Symbol of the world's most experienced sealmaker*

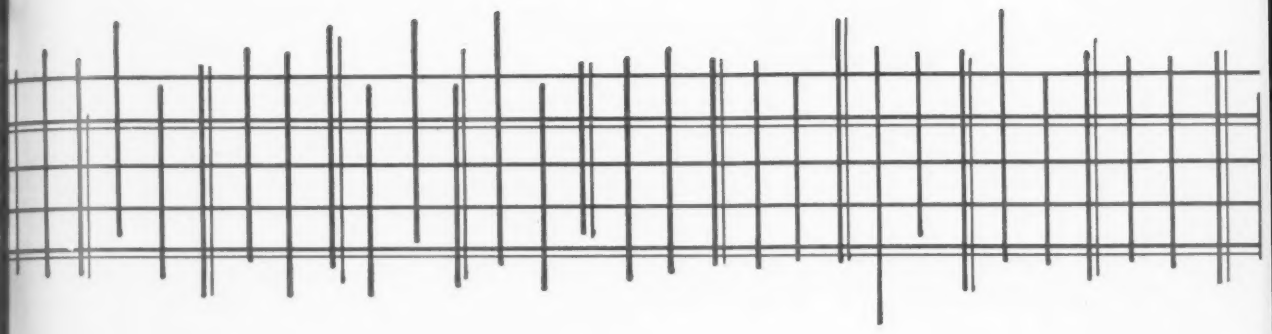


**K Seals** *have the finest "on the job" record of any static metal seal in the aircraft and missile field*

*Harrison* **Manufacturing Co.** *2908 N. Naomi St., Burbank, California Telephone: Victoria 9-4585 TWX: BRB 4416*

**Represented Nationally by Harold E. Webb Co.**
*1307 N. San Fernando Rd., Burbank, California Victoria 9-4144*

*Representatives:* New York Los Angeles Denver San Diego Seattle Phoenix Huntsville



# genus: homo · species: sapiens discipline: factors engineering

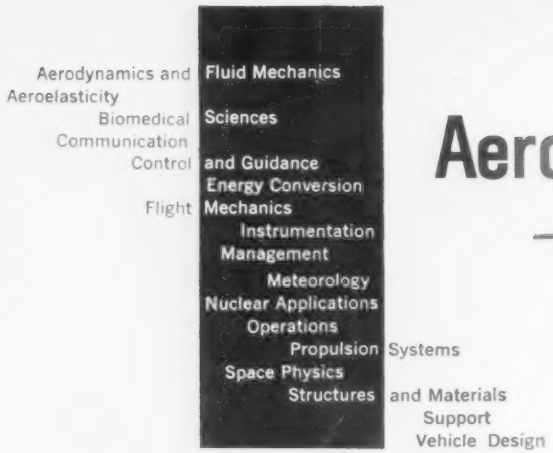
At the six major RCA Defense Electronic Products facilities, teams of psychologists and design engineers are deeply involved in the highly specialized, incredibly complex study of human factors engineering—man/machine interfaces, auto-instructional methods, decision processes, read-in/read-out optimization techniques, sensory perception, the entire spectrum of psychological-physiological-physical disciplines.

Whether your requirements involve human factors study of command and control functions for defense networks, or projected life support systems for space exploration, a total RCA capability stands ready to assist you . . . from feasibility study to project completion. Write Defense Electronic Products, Radio Corporation of America, Camden, N. J.

RCA®

The Most Trusted Name in Electronics

RADIO CORPORATION OF AMERICA




# Aerospace Technology

## —as seen by the panels

## Support

### *Lunar Support Equipment— The Time Is Now*

Gilbert Rolan

Mr. Rolan is a member of the IAS Aerospace Technology Panel on Support, and Manager of the Aerospace Equipment and Systems Project Office—American Machine and Foundry Company Greenwich Engineering Division.

MAN WILL BE ON THE MOON before the end of this decade. This is assured by the emphasis now placed on a manned lunar landing by our political, military and scientific communities. Will this voyage be a useful expedition which can benefit mankind? The answer to this question lies in the answer to another question. Will the special support equipment needed to accomplish the desired tasks be available?

The equipment required for propulsion, navigation, guidance, computing, communications, and checkout has been widely publicized and is sufficiently complex and expensive to receive detailed attention of industrial and governmental scientific agencies. These are being developed with speed.

We are concerned here with the less glamorous, but nonetheless essential, "hammer and anvil" type of ground support equipment required to accomplish useful work on the lunar surface—lunar support equipment. If man is to be mobile, traversing devices are required. To build a permanent base, tools such as drills, muckers, bulldozers, shovels, wrenches and hammers will be used. There is no off-the-shelf equipment on the moon. Ordinary, everyday construction and maintenance tools and equipment will be required in a new form, a form compatible with the lunar environment and with the restrictions and handicaps under which man will work if he is to do anything more than plant a flag and come home.

It has taken us many years and many mistakes to learn that ground support equipment, to be effective and reliable, must be developed simultaneously with the airplane and the missile. This experience is particularly applicable to lunar support equipment, in view of the enormous cost of even a single mission and the complete dependence of the humans who will operate it.

There can be no compromise with reliability in such equipment. The degree required can only be obtained by allowing sufficient development and test time for each component—time to eliminate every possible failure point and to determine and provide for every combination of operational conditions which may be encountered.

To provide this all-important development and test time, the effort must start now!

Ideally, such a program is based on known, established criteria, substantiated by recorded experience with the same or similar applications. This is not the ideal situation. Recently there has been increasing emphasis on engineering studies aimed at defining the scientific and engineering breakthroughs needed to establish a manned lunar base. These studies have highlighted the fact that definitive information about the lunar environment is infinitesimal compared with that available on space environment. This gap widens daily as more data are received from orbiting satellites. It is no surprise, therefore, that most of the studies to date have concentrated on trajectory analysis, propulsion analysis and basic space ship configuration and design.

Despite this lack of definitive data on lunar geology, terrain and environment, there is definite agreement on the general problems which will be encountered and the approach to their solution. Depending on the criteria established for the manned lunar base, the studies show wide agree-

ment on the base arrangement and type of equipment required. For example, although our ability to accurately forecast the intensity or frequency of solar flare radiation is questionable, there is no question that protection must be provided against this hazard. Consequently, most of the studies have concluded that a permanent base must be constructed beneath the lunar surface or shielded against radiation by covering with lunar material.

It is obvious that lunar equipment and construction techniques cannot be optimized until scientific packages, capable of collecting and transmitting definitive data back to earth, are landed on the moon. However, component and equipment development, based on the range of scientific opinion on lunar geological content and terrain, can be started immediately. Although this effort will require parallel programs which may involve a few dead-end projects, and frustrating time-consuming regressions and reorientations, this cost will be low when measured against the cost of an eventual crash program or the political implications of not being ready with lunar support equipment when man is ready to land on the moon.

Man will certainly be on the moon in the near future. He will need lunar support equipment. The time is now—for development of that equipment.

✦ ✦ ✦

# Space Physics

## *Environment for Manned Space Flight*

John C. Evvard, AFIAS

The author is Chairman of the IAS Aerospace Technology Panel on Space Physics, and Assistant Director of Lewis Research Center—NASA.

THERE WAS A TIME not so long ago when studies of the environment beyond the upper atmosphere were principally the concern of physicists and astronomers. But times have changed! The whole world now looks forward in anticipation to the first manned lunar landing. The many IAS members who are actively supporting Project Apollo recognize the strong need for a better knowledge and understanding of the environment through which the "lunarnaut" must fly. Electronic and human systems must be shielded against the hazards of this environment. Thus, space physics becomes of interest and part of the business of the aerospace scientist.

Clearly, the first manned lunar spacecraft cannot be protected against all hazards that our solar system and galaxy might produce. Any one of many dangers could feasibly cause a mission abort or more serious consequences. The aerospace scientist must decide which of the many environmental factors are most hazardous for a given mission and provide the necessary protection.

The philosophy of the first "lunarnautic" flight will surely be to take reasonable chances on this short duration trip so that the spacecraft and its radiation shielding can stay within the weight lifting limitations of the launching vehicle. Both by data and by analytical studies, the proper compromises between shielding weight and survival probability must be determined. Whatever this compromise, the design of the spacecraft should be optimized to give the greatest protection for the least weight. Fuel, water, and supplies might, for example, be used as shields.

Weight limitations may restrict the Apollo shield to between 10 and 30 gm/sq cm. This relatively thin shield will protect the man for the short times that he might spend in the Van Allen belts and against minor and major solar flares. His greatest danger could come from unpredicted giant solar flares.

Almost all protons of energy greater than 100 to 200 mev will pass through a 10 to 30 gm/sq cm shield. These energies are prominent at flux levels as high or higher than $10^4$ protons/sq cm sec for a type III-plus solar flare. The radiation dose to the crew of about 25 rem is almost entirely due to these protons for a short-term moon flight.

The energy loss mechanism (ionization and straggling) in thin shields is well understood. Hence, the uncertainties in the dose to the crew arise chiefly from an inability to predict the sun's "weather" and the occurrence time of major and giant solar flares. Major flares on the average occur monthly. Only 7 giant flares have been observed during the past 18 years.

There is hope that solar flares can be predicted a few days in advance.[1,2] If such predictions could be extended to weeks, the mission could be planned to avoid times of solar disturbances and hence the shielding weight could be reduced.

Without the ability to predict the occurrence of giant solar flares, the first manned lunar mission must depend upon a strong mission abort capability for protection against this phenomenon. The solar physicists thus have the very important task of improving the predictability of the sun's behavior.

In thin shields (10 to 30 gm/sq cm) protons will collide only occasionally with a shield nucleus and,

(*Continued on page 79*)

# Naval Attack Aviation

Richard Hutton, AFIAS
*Grumman Aircraft Engineering Corporation*

Fig. 1. A2F-1 development.

Mr. Hutton, Grumman's 21st employee and the IAS Lawrence Sperry Award recipient in 1945, is Vice President—Engineering. He began his career as a mechanic with Loening Aeronautical Corp. in 1928, and in 1930 joined the newly formed Grumman organization. After serving as a Project, then Development, Engineer, he was placed in charge of Preliminary Design. He became Chief Engineer in March 1955, having won the Sperry Award for contributions to the design and development of the F4F Wildcat, the F6F Hellcat, and the TBF Avenger.

THIS PRESENTATION will endeavor to outline, from the contractor's viewpoint, opinions on what is needed and what lies within the state of the art of technological development for naval attack aircraft within the time period from 1965 to 1975.

As is now known, we have under development a naval attack aircraft designed for limited war—a program that has been receiving our most serious attention for the last 3 years. We would not be engineers, however, if we did not concurrently look ahead to what lies beyond, and it is equally understandable that we look ahead from within the framework of what we are now doing.

A significant point should be made; the result of the current rate of technical development is that there are often more new directions in which we can go than can be combined into a single new system, and more new directions than the country can afford to develop all at once. It is, therefore, almost impossible for the contractor alone to pick the combination of new capabilities which will make the ideal new weapon system. For these reasons, therefore, no attempt will be made to define a specific attack weapons system which may follow what we have today. Rather, the A2F will be used as a base, and described briefly, to indicate a few of the many directions in which advancement is desired.

These comments are necessary because they represent the state of the art in fleet attack systems which will be operational in 1965 and the base from which further developments will be measured (Fig. 1).

The A2F-1 is basically a product of the Korean conflict—a limited war which did not expand into an all-out war, but also a limited war which we did not win. One of the contributing reasons for our not winning it was the lack of certain weapon system capabilities; many of these needed capabilities were compiled in the Development Characteristic for this attack system which became available in 1956—with a go-ahead in 1958—and which is now in flight-test status.

More important than how far we have come, however, is how far we have to go. The current production planning of the Bureau of Naval Weapons calls for operational squadrons in 1963. Based on the history of previous attack aircraft, it is not out of order to describe the A2F-1 or -2 or some other number as representative of the most advanced naval attack system that will be fleet operational in the 1965 to 1970 time period. However, by 1970 a new and far more advanced system will be under development, and it is this machine that we shall describe here.

Naturally, it will have greater payload capability, greater range, perhaps much greater speed, more accuracy, more versatility, and will be able to operate in a broader environment. But greater, longer, faster, more accurate than what? Let us spell

# for Limited War • 1965–1975

*. . . in which the A2F is used as a base "to indicate a few of the many directions in which advancement is desired."*

out briefly the qualitative capabilities of the A2F-1 in the 1965–1970 time period.

It will carry a weapon load in excess of 15,000 lbs on an interdiction mission, going all the way in and out at sea level if necessary. Because there is complete fuel and weapon interchangeability, it will also carry a single weapon on an unrefueled deep-penetration mission to a radius sufficient to reach any target in a limited-war theater. This is regarded as a tremendous improvement in limited-war attack capability compared with the systems already operational with the fleet.

To provide the necessary versatility for a rapidly changing limited-war situation (Fig. 2), this system incorporates an airborne digital computer. One of the most significant technological steps of the past few years, the airborne digital computer enables the A2F to deliver its weapons over the entire spectrum of delivery modes from level bombing, to toss, to lay-down, at any speed, altitude, and attitude from which the aircraft may find it convenient to approach the target; it constantly computes the proper release point for any weapon based on aircraft speed, altitude, and heading relative to the target.

One of the most sobering disappointments of the Korean conflict was the high percentage of attack weapons which missed their targets. Thus, one of the most important single contributions that this weapon system offers is the large increase in accuracy of the overall system—the ability to deliver its weapons with an accuracy more than three times greater than Korean experience under zero-zero target weather conditions. These accuracy capabilities are combined with a Doppler-corrected inertial navigation system with a maximum drift of less than 4 mph. To obtain the desired delivery accuracy, it will continuously track the target by means of a high-resolution radar and feed this information directly to the digital computer. Identification of small mobile targets under battle conditions, the airborne moving target function of the search radar, is a valuable asset even in daylight. With these characteristics, the all-weather capabilities of the aircraft come almost "for free." The basic justification of the electronic system is to ensure target acquisition and delivery accuracy, not to provide all-weather operation.

The variety of weapons accommodated should also be mentioned (Fig. 3). In actuality, every attack weapon being developed by the Navy can be carried, and all can be delivered (including the Bullpup), without having the target ever seen by the naked eye. Fig. 3 shows the five basic inboard stations equipped with Douglas (*Continued on page 34*)

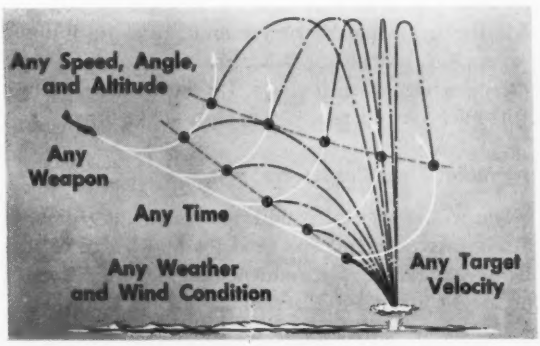
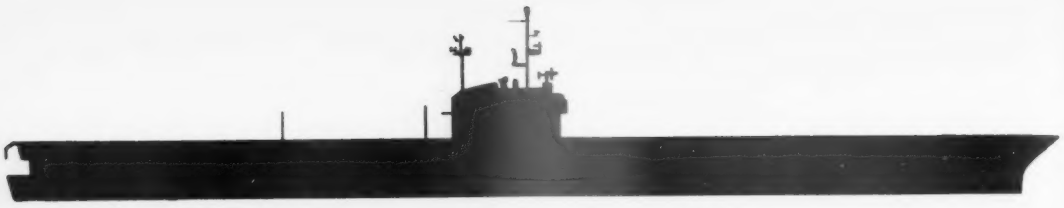



Fig. 2. Delivery capability, 1965.



Forrestal

# The Fleet Carrier Attack Problem in Limited War

George R. Gehrkens, MIAS
*North American Aviation, Inc., Columbus Division*

A limited war is a war limited in one or more of the following aspects: Methods, number of belligerents, area and objectives. Quoted from "Limited War —The Challenge to American Strategy," Robert Endicott Osgood.

WHETHER by Mr. Osgood's definition, or by any other authoritative standard, limited war is, at best, a broad term used to define a wide range of conflicts (Fig. 1).

More important than the precise definition of the term limited war, however, is the growing number of disputes and armed conflicts. Furthermore, a measurement of the current world geopolitical situation by our World Conflict barometer indicates a definite trend toward probability of United States participation in the more critical type of conflicts (Fig. 2).

These basic characteristics of the present situation, the extreme fluidity and closeness to a limited war state in many areas, emphasize the critical need for a highly developed limited war attack capability.

Development of this capability not only will provide the requisites for timely and successful limited war action, but also will add balance to the global war deterrent stature of the United States because of its effectiveness as a postnuclear strike force.

### The Major Fleet Carrier Problem

The wide range of conditions which may prevail in a limited war and the need for knowledge of the enemy have a decided influence on the definition of the Fleet Carrier's role in such conflicts. Knowledge of the enemy prior to the overt development of a limited war situation is obtained by conventional intelligence procedures, plus such supplementary means as may be appropriate to world conditions. Upon the initiation of actual combat engagements, the Carrier Task Force Commander will be confronted with rapid fluctuations in both the defensive and the offensive posture of the enemy which make proper target orientation extremely difficult. At the same time, he will be confronted with the difficulty of exacting the maximum strike potential from the resources at his command. It is within this context that the attack problem of the Fleet Carrier in Limited War and the purpose of this examination of the problem must be defined.

### Availability

One of the major factors contributing to the difference between attack potential and attack effectiveness is the degradation in aircraft availability. Over the years, there has been a steady decline in the number of aircraft that can be relied upon to perform their missions. Aircraft availability aboard the fleet carriers has been as low as 50 percent for complex systems. To indicate the seriousness of this problem, the attack potential for a present-day Fleet Carrier has been calculated in terms of the number of targets that could be destroyed (Fig. 3). The targets considered were normalized in distribution, size and hardness and a weapon delivery accuracy of 100 ft CEP and a 0.5 target kill probability was used. Obviously, the availability problem must be solved. Fleet Commanders should not be expected to perform their missions with only "half squadrons."

But availability of aircraft is a complex function of many variables involving the vehicle, its environ-

*Confronted with rapid fluctuations in both the defensive and the offensive, the Carrier Task Force Commander will also face the difficulty of exacting the maximum strike potential from the resources at his command. Essential to this enterprise, in addition to good reconnaissance, is a light-attack, low-cost, readily maintained aircraft with navigation systems and electronic countermeasures equipment sufficient to assure all-weather day or night delivery of weapons against visual targets defended by guns, missiles, or interceptors.*

ment, the personnel and maintenance facilities, and the logistic supporting system. On a single-vehicle basis, the gross size, the amount of complex equipment, the accessibility of this equipment, the usage rate of the vehicle, and the reliability of the various components are among the most important factors affecting availability.

The obvious solution to the problem of increasing Fleet attack aircraft availability is simplicity and reliability. Herein is the basis for the concept of low-cost, light-weight, reliable attack aircraft with a large ordnance tonnage delivery capability and only the minimum of maintenance required.

Mr. Gehrkens, who will observe a quarter-century with North American on May 10, 1962, is Vice President and Chief Engineer of the Columbus Division. During 14 years at the Los Angeles Division, he was Project Engineer (later Ass't. Ch. Proj. Engr.) on three fighter aircraft (among them the P-51 Mustang) and two bombers, and Project Engineer on missile projects being initiated in 1946 and '47 by the Aerophysics Division. Under his direction since 1951, the Columbus Division has participated in either the initial design or full design and development of nine aircraft and a target missile. Its engineering staff has been expanded from 50 to more than 3,000, with an average level of experience approaching 15 years per man, and value of facilities has increased from $75,000 to more than $12 million with about 30 laboratories contributing to advancements in many scientific areas.

**Attack Potential Increase**

Normal state-of-the-art development will provide a considerable improvement in the reliability of attack aircraft and a resulting increase in Fleet Carrier attack potential. However, in order to satisfy the basic requirement of limited war—accurate delivery of quantities of high explosives on specific targets—a counter must be provided for the concurrent improvement in reliability and availability of enemy defense systems. It is probable that this countermeasure will be provided by a limited inventory of stand-off ASM's, guided weapons, such as the "ARM," and electronic "fire power" ECM.

Current research and development progress gives assurance that several reliable weapon guidance systems (such as television, infrared, contrast differentiators, image lock-on devices, etc.) can be made available prior to the 1970's. Systems such as these will permit a high-performance VA (heavy attack aircraft) to deliver ASM's and guided bombs with a very high degree of accuracy. The most sophisticated limited war defense systems could thus be attacked with a very high target kill probability and high VA survival. The full spectrum of targets would then be vulnerable to the increased high-explosive (HE) delivery capabilities of the light-attack aircraft.

Since the cost of guided weapons is an important consideration, it should be pointed out that, although there will be a significant increase in target kills due to the effect of these weapons on the enemy's defensive systems, actual use of the weapons will be limited to priority type targets.

However, the weapon guidance packages should also be adaptable to light-attack aircraft for use against important point targets located in areas free of sophisticated defensive systems.

(*Continued on page 38*)

# Problems of Antisubmarine Warfare

John E. Clark

*Rear Admiral, United States Navy*

ONE OF OUR Navy's most vital continuing tasks is antisubmarine warfare. This embraces many and varied techniques, vehicles, and scientific approaches, singly or in combination, and subject to constant change. Those concerned with this important phase of warfare must work simultaneously toward two often diverse purposes. The first is the provision of the most immediate means of carrying antisubmarine warfare to the enemy. The second is the long-range evolution of advanced concepts for future employment.

Antisubmarine warfare is no man's private preserve, and to solve it requires the nicest kind of teamwork involving a variety of vehicles—aircraft, ships, submarines, and surface systems of many types.

### The Role of Aircraft

From now on, aircraft can and must assume a larger part of the load because destroyers will be called on for many missions and will thus be stretched exceedingly thin. As a corollary, aircraft can be produced more quickly in the numbers required and their crews can be trained more quickly; a vast expansion of our antisubmarine warfare capability will also be mandatory if war comes. Aircraft will be utilized because the equivalents of the sonar are inherent in the Julie and Jezebel types of systems with Echo ranging, and in the improved deep-dunking helicopter sonar, plus the latter's breakthrough in all-weather operations. When Jezebel becomes a deep-listening device, we shall be well on the road.

As it stands now, the task requires the coordinated efforts of many team members, and, anticipating advances in surface-borne weapons and other devices, it will always be done better that way. It is essential that aircraft advance in order to carry the burden it may have to accept in larger measure. Air ASW is not a problem of aerodynamics, but rather of what may be called sensory sciences.

Therefore, research and applied research would be as much in support of subsurface vehicles as of airborne. It is not the high-performance aircraft that concerns us so much as the equipment the aircraft carries. It is granted, of course, that the bulk and weight of equipment will affect airplane design and, in turn, aerodynamics. So, too, may the mode of operation of the equipment and interference problems affect the airframe design. For example, in order to be used with the helicopter, the magnetometer must be well clear of the aircraft—either suspended or mounted on a retractable outrigger. The S-82 radar certainly made the airborne early warning aircraft look like something no one had ever seen before, and it represented a serious design problem.

It is conceivable that with the advancing state of the art, aircraft ASW equipment, and installation of

Essex

*What constitutes combat readiness?*

- ***A brief appraisal of our performance capability, new weapons and equipment, and the interrelationship of subsurface and airborne vehicles.***

high-powered sonar in the carrier, and Essex-class carrier with two destroyers could be, while not the best, a useful hunter-killer unit. It is a scheme that may be forced upon us.

Our overall readiness, the various factors that influence it, and our current status in these major areas must be studied thoroughly.

**The Threat**

We must begin by examining the threat. The submarine threat we face consists of two entirely different and unrelated problems—(1) the missile launcher, the Polaris submarine, and (2) the anti-surface ship submarine, the convoy attacker. The mission of the first is achieved by stealth, moving slowly and quietly, and avoiding any and all contact. The mission of the second requires daring maneuver, high speed, noise, and the seeking of contacts for aggressive action. So preoccupied with the former have we become, probably because it involves awesome nuclear war, that we have lost sight of the latter though it is much more likely to be employed and is more crucial to our success in a major war or even a minor one. More submarines will surely be present in future Korea-type conflicts.

In the case of the missile launcher, while the threat may be remote, we must nevertheless accelerate our R&D efforts toward solution. In the case of the second threat, the convoy attacker, we are much more advanced technologically, but not nearly advanced enough, and we are lacking in numbers. Failure to prevent the severance of shipborne communications with our allies means defeat. R&D in ship and airborne classification detection devices must be accelerated to the maximum.

One must realize the magnitude of the problem itself. On an average day you will find a pattern of 2,700 ships plying the trades in the Atlantic and 3,300 in the Pacific. We must make sure that the oceans continue to unite us with our allies and our sources of important raw materials by preventing the Soviet submarine fleet from negating our control of the seas and isolating us.

The other major task is to cope with the potential missile-launching submarine threat off our coast. Undoubtedly, this threat is building up and, in any event, we must be ready for it.

Or perhaps the threat is of still a different kind—something like a limited war—involving, however, the threat of submarine opposition for a change.

A strong ASW effort during any such limited conflict might well serve to prevent this small-scale war from growing into a nuclear holocaust.

If the nuclear exchange did occur, the final outcome might well be determined in a third and final phase in which the ability to survive and resupply would prove decisive. Since naval forces, and submarines in particular, have a probability of survival in a nuclear exchange, ASW could be a dominant factor in this final phase.

Considering the larger problem, our ASW strategy breaks down into the following plan—a forward offensive, which consists of making strikes at submarine bases and other support facilities and maintaining submarine patrols in (*Continued on page 40*)

**Admiral Clark, Commander of the Pacific Missile Range, Point Mugu, Calif., has had a distinguished career as a naval officer. Recent highlights in his 34 years of naval service include assignment (1955) as Director of the Guided Missiles Division, office of the Chief of Naval Operations, at the conclusion of which he was commended by the Secretary of the Navy for meritorious service. In 1958, he became Deputy Director of the Advanced Research Projects Agency, Office of the Secretary of Defense, and for meritorious service in that capacity received a Letter of Commendation from the Secretary of the Navy with authorization to wear the Bronze Star in lieu of a Second Commendation Ribbon. In addition to having received many of his country's decorations, Admiral Clark has been awarded the Order of the British Empire (Honorary Officer).**

# The Missile Threat—

## Future Anti-Air Warfare

W. Paul Thayer, AFIAS, *Chance Vought Corporation*

IN THE PAST 50 YEARS, naval air warfare not only was born but has progressed to a complex, sophisticated science. During the latter part of these first 50 years, improvements in aircraft performance dictated that there be a mixture of missiles with the more conventional armament carried by fighters, interceptors, and warships. The most significant change that will influence the next 50 years of anti-air warfare is not any specific change to any individual system, but rather the rate of change of technology. In the latter part of the first half-century of naval aviation, this rate of technological change increased rapidly. A single advance in technology tends to open two or more paths for offensive and defensive systems. Thus, the capabilities and generally the complexities of systems will increase as an exponential function rather than a strictly linear function. We can already see the beginnings of the changes that will characterize the next 50 years. Free-fall weapons are being replaced by medium- and long-range stand-off missiles. These missiles will be equipped with homing and other types of terminal guidance. The feasibility, and in fact the demonstration, of space vehicles as a significant threat to the Fleet is near at hand. Perhaps even more significant than space systems in the next 50 years will be the threat posed to the Fleet from weapons launched from deeply submerged submarines or from even more exotic subsurface vehicles. The problems of detection, classification, and identification are becoming more difficult as the threat becomes more long range in nature, and will become especially so when long-range stand-off weapons are combined with a very-low-altitude or a very-high-altitude capability.

A broad look at expected trends in Fleet defense indicates that two basic problems will continue to plague us for some time. These problem areas are, first, system response time available—i.e., the time available to detect and identify a threat and launch a weapon; and, second, the continually increasing cost of modern defensive weapon systems. If our efforts to continue to provide effective Fleet defense are to prosper, these two problem areas must be vigorously attacked and overcome.

Mr. Thayer was born in Oklahoma and attended the University of Kansas. He saw service in World War II as a Navy fighter pilot and received, among other decorations, the Distinguished Flying Cross with two stars. Joining Chance Vought as a test pilot in 1948, he became Sales and Service Manager in 1953, Vice President for Sales and Service in 1954, and Vice President and General Manager of the Aeronautics Division in 1959. In August 1961 he assumed his present position as President of the Chance Vought Corporation, a subsidiary of Ling-Temco-Vought, Inc. In addition to being a Director of LTV, Mr. Thayer is Chairman of the Board of the Harbor Boat Building Co. and a Director of Vought Industries, Inc. He is a National Vice President of the Navy League of the United States, a Vice President of the Conquistadores del Cielo, and a member of the Society of Experimental Test Pilots and of the American Astronautical Society.

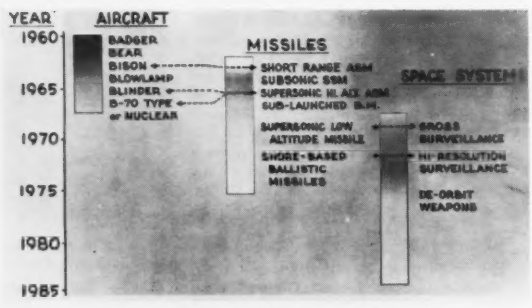



Fig. 1. The threat to the Fleet—time vs. type.

*Fleet defense, during the next 50 years, will have shifted vastly from threat by aircraft to that from missiles and space vehicles. Thus, a survey is made of the defense problems, and an evaluation given of probable threats and several defense-system concepts.*

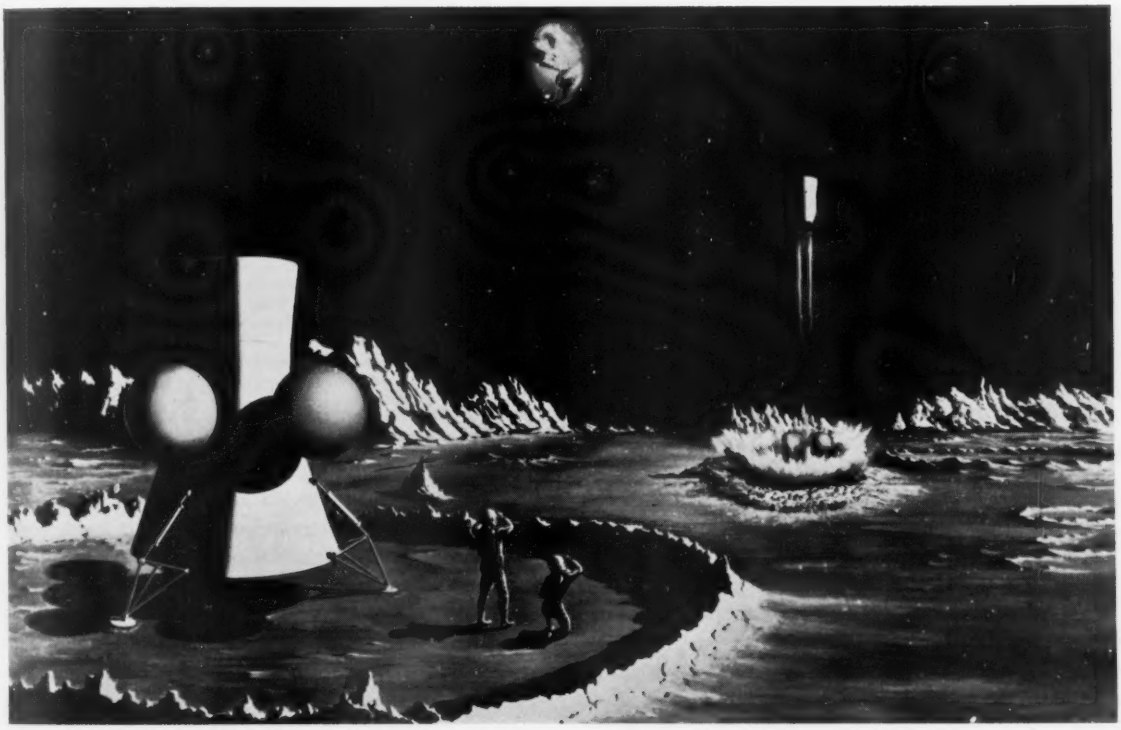


Fig. 2. Lunar base.

To illustrate the two problems, reaction time and cost, let us take two specific examples.

Assume a high subsonic attack from an altitude of approximately 45,000 ft. The defensive system reaction time will be approximately 30 min. Merely moving this subsonic threat down to an altitude of approximately 500 ft in place of 45,000 ft will reduce the reaction time by approximately 15 to 1, or down to about 2 min. Not only is the reaction time reduced with increases of speed and decreases in altitude, but so are the problems of detection, tracking, and guidance. Nuclear propulsion is feasible for airborne systems and there is every reason to expect that the next 50 years will see nuclear propulsion applied to extremely low-altitude vehicles which can become a primary threat to the Fleet. The reaction-time problem is rapidly catching up with available technology.

Now the cost problem. During World War II, the approximate cost of a 5-in. antiaircraft shell was $100 and the installation of a single mount, including simple fire control, was approximately $100,000. Today, the procurement of a single long-range surface-to-air missile might cost in the neighborhood of $250,000, and the associated launching and fire control equipment many (*Continued on page 43*)

# Rapid Sea-Wide Supply

Donald W. Douglas, Jr., AFIAS

*Douglas Aircraft Company, Inc.*

The author is President of Douglas Aircraft Co., which he joined in 1939 after completing engineering studies at Stanford University and Curtiss-Wright Technical Institute. After a 6-month phase in the engineering strength group, he was transferred to the DC-3 Project, specializing in power-plant installation, and was subsequently assigned similar duties on the DC-4. After discharging increased responsibilities during World War II and in postwar years, he was elected Vice-President in 1951, and a Director in 1953. Elected President in 1957, Mr. Douglas is active in numerous civic and professional organizations, and in 1960 was awarded the National Management Association's Gold Knight of Management.

AN EFFECTIVE sea-wide supply system for the future is hinged inexorably to the development of new techniques for faster replenishment of ships at sea.

The chief requirement for such a system is that it be a rapid-reaction one. It must accommodate the unexpected loss of a critical distant base, or loss of some other element of a necessarily complex lifeline. It must be able to react with unusual speed to support any action—whether spontaneous or following a sequence of events merely indicating a possible need for optimum supply measures. It can be no less than an all-conditions operational organization prepared for eventualities some of which may now seem unlikely or impossible.

Together, these requirements present us with a problem. In studying it to arrive at answers of significance to naval aviation's future, it has become clear to the author that a new form of ocean-going transportation is needed—that is, if we are going to attain a very real advance in our sea-wide supply system. Of course, existing systems can, and should, be improved, and examples will be listed. However, aircraft systems to supply ships at sea will remain limited in capability to transport very heavy bulk cargo, and conventional supply ships are not only slow but extremely vulnerable to submarines.

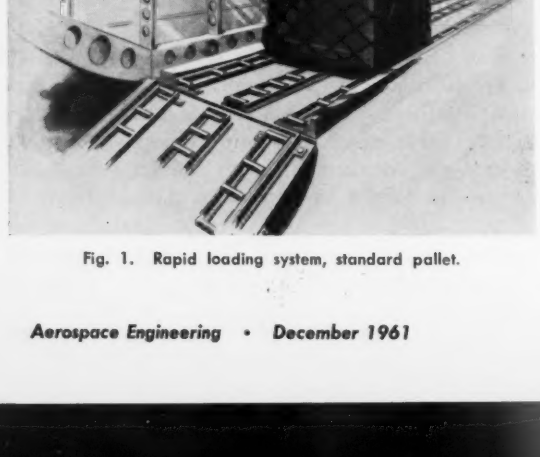


Fig. 1. Rapid loading system, standard pallet.

Accordingly, recommendations for development of our sea-wide supply system are made in two parts. For the immediate future an extension of proved concepts is suggested, but for the long pull a rather radical departure from convention is shown to have very real promise.

The COD, or carrier-onboard-delivery, system that we now have represents the elements of a rapid supply system and needs to be fully implemented.

To facilitate loading and unloading of the COD airplane on the carrier, and on shore, a rapid cargo-handling system is required. This system could be similar to that currently being implemented in our Air Force 463L project. The objective of this proj-

**A real advance in sea-wide supply requires a new type of ocean-going transport. For the immediate future, improvement of existing systems is suggested; but for long-range development, a "carrier-onboard-delivery" system based on the use of large GEM's is shown to have real promise.**

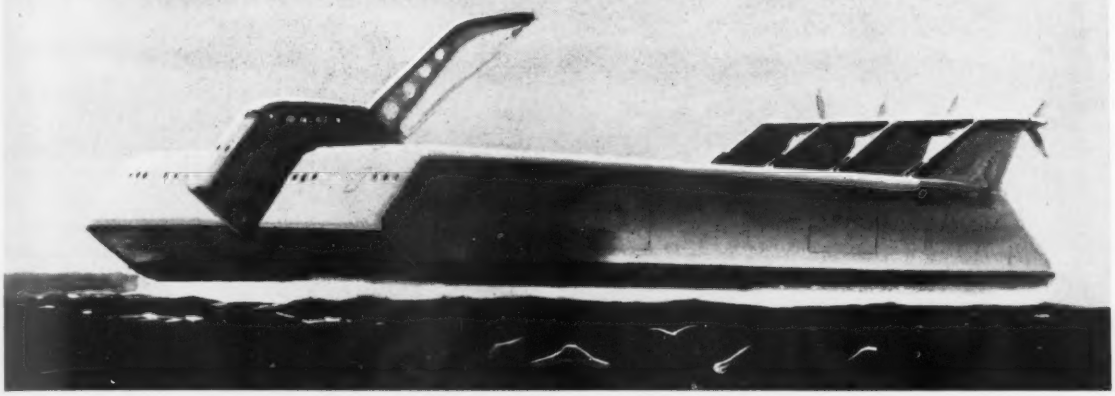


Fig. 2. Ground Effect Machine shown as possible supply ship.

ect is to provide a materials-handling support system that will permit the fullest exploitation of the flexibility, speed, and economy inherent in air transportation for MATS, Logair, and commercial users. The 463L program is involved principally with cargo-handling procedures and techniques. It includes a definition of terminal design, cargo sequencing, packing, consolidation, and handling from the cargo manufacturer to the overseas user.

A basic element of the 463L system—which could be adopted by the COD system—is *a "standard" pallet which will fit in any aircraft*, will slide easily in and out of the fuselage on roller bearings, has guide rails, and has a quick-latching-and-restraining harness arrangement (Fig. 1).

The use of this pallet by the COD aircraft should permit inbound cargo to be removed and replaced with outbound cargo during the time necessary to accomplish a pressure refueling operation. This would increase the airplane productivity, and it would minimize the time of carrier tie-up while handling cargo.

The COD system also needs a new transport airplane having short take-off and landing characteristics; one that is designed to include the new, rapid, cargo-handling system; and one that can carry greatly increased payloads, of the order of 8 to 10 tons, for ranges in excess of 1,500 miles. Consideration, for the immediate future, should also be given to the use of obsolete or mothballed carriers to receive, and act as the redistribution focal point for, COD resupply.

This COD system, either with or without the mothballed carriers, will continue to be used to provide the urgent weight-limited resupply. It has, however, two fundamental limitations from the total Navy point of view. First, ships requiring the resupply may not be near, or in company with, a carrier; and secondly, the bulk and tonnage of cargo which this system can supply—and the time and cargo space the attack carrier can devote to this purpose—are very limited.

The application of nuclear propulsion to all ships in the fleet would greatly reduce the preponderance of bulk cargo; however, the requirements for airplane fuel on the carriers—for ammunition, conventional bombs, rockets, missiles, warheads, and groceries—are still beyond the capability of the COD supply system.

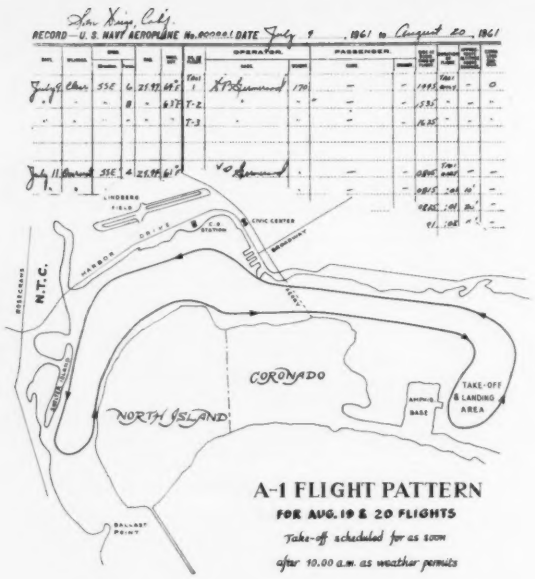
The advance, which I indicated earlier as a radical departure from convention, is a new type of vehicle. In England, it is referred to as a "Hovercraft." In ONR terminology, it is referred to as a GEM or Ground Effect Machine. Fundamentally, this new vehicle is an *aircraft* which flies in close proximity to the ground or water, as the case may be; the larger it becomes, the better its economic or operating efficiency.

The GEM illustrated in Fig. 2 might be a typical unit for rapid sea-wide supply. It is clear that we are *not* talking about the small devices which are currently being built, but of craft which will handle large weights and volumes of cargo at high speed. The configuration will tend (*Continued on page 62*)

# Airborne With

D. P. Germeraad, AFIAS

*General Dynamics Corporation, Convair Division*



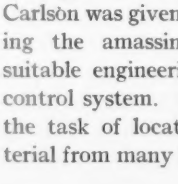

A REPLICA of the Navy's first aircraft, the Curtiss A-1 Hydroaeroplane, lifted from the waters of San Diego Bay during August, 1961, to commemorate the Golden Anniversary of Naval Aviation.

How did this page torn from history come about? In 1958, the San Diego Section requested National Office approval of a joint IAS/Navy National Naval Aviation meeting during 1961 in recognition of Naval Aviation's fifty years of phenomenal growth. This was granted. The writer, then Section Chairman, appointed J. G. Wenzel as General Chairman. Jim, an energetic, dynamic individual, immediately put plans into motion to make this the most successful program ever held. The outstanding events that took place last August indicate how completely he succeeded.

Part of this program as envisioned by Jim was the building and flying of a replica of Glen Curtiss' A-1. Lt. Ellyson, Naval Aviator No. 1, had completed his early flight training, flying the A-1 as a seaplane from San Diego[1] (Figs. 1 and 2). These flights represented the first officially sanctioned by the Navy. The replica A-1 was to re-enact this operation.

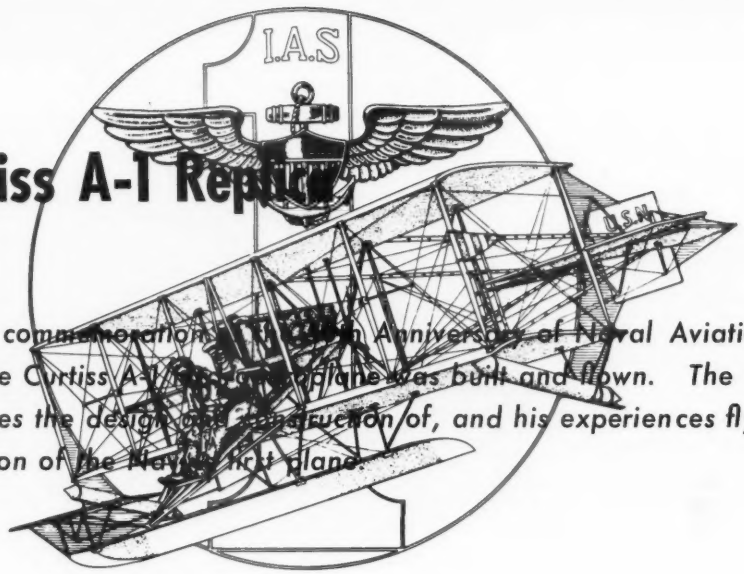
Following considerable discussion with high-ranking naval officers, the program gathered momentum. Fred Verville, famous many times over for his design and engineering ability, was appointed by the Navy as Chief Technical Advisor. After arduous research and delving into dust-covered archives, Fred emphatically stated, "Yes, we do have sufficient information to proceed with the construction of a replica!" Invaluable engineering drawings made on a hangar wall at Hammondsport, New York, had been lost forever when the janitor white-washed the wall. However, by careful scrutinies of authentic photographs, nebulous areas were pieced together. The project was definitely underway.

Bill Immenschuh of Ryan Aeronautical Company was appointed Project Director by the IAS. Vince Carlson was given the monumental task of coordinating the amassing of engineering data, creating suitable engineering drawings, and redesigning the control system. Bill Cocherell was challenged with the task of locating and procuring parts and material from many helpful donors, and supervising air-



Mr. Germeraad, Chief Engineering Test Pilot for General Dynamics/Convair, San Diego, is currently engaged in the Convair 990 jet airliner FAA certification test program. Born in Billings, Mont., he graduated from Billings Polytechnic Institute and received the Shell Intercollegiate Aviation Award. He attended MIT on a Convair fellowship (1948–50) and was granted a B.S. degree in aeronautical engineering. There he received the Salisbury Memorial Award as the outstanding aeronautical student during his senior year and became a member of Gamma Alpha Rho, honorary aeronautical fraternity, and Tau Beta Pi, honorary engineering fraternity. He flew throughout the Pacific Theater as a Navy pilot during World War II, receiving the Air Medal for action against the Japanese. A Commander in the U.S. Naval Air Reserve and Commanding Officer of a BuWeps Representative Training Unit based at Naval Air Station, North Island, special Navy orders were written to authorize his replica Curtiss A-1 flights. Mr. Germeraad joined Convair in 1946 as a production co-pilot. He later was made flight captain and in 1951 transferred to Engineering Flight Test. He has test flown many Convair aircraft including the L-13 Hall Flying Car, XP5Y-1, the 80-ton R3Y-1 and R3Y-2 turboprop Navy Transports, the XF2Y Sea Dart, the F-102 and F-106 Interceptors and military and commercial versions of the Convair Liner twin engine transports. In 1960, he was selected Convair Management Club Award recipient for the greatest individual contribution among 18,000 employees. He is a past chairman of the IAS San Diego Section, a member of the IAS National Council, a Fellow of the Society of Experimental Test Pilots, and an Associate Fellow of the RAeS.

# the Curtiss A-1 Replica




*As part of the commemoration of the 50th Anniversary of Naval Aviation, a replica of the Curtiss A-1 [illegible] airplane was built and flown. The author describes the design and construction of, and his experiences flying, this reproduction of the Navy's first plane.*

craft fabrication—all with essentially volunteer labor. Fred Verville kept a steady hand on the operation to insure authenticity.

There were a few differences between the original A-1 and the replica. The original was controlled in pitch by elevators connected in the present conventional manner using a control stick. However, directional control was accomplished by turning a control wheel which moved a small, all-movable vertical fin. Banking was a neat trick—a shoulder yoke moved the ailerons when the pilot's body was moved from side to side. This way, if the pilot saw the water coming up too fast on one side, by instinctively pulling away he would move the ailerons, thus righting the aircraft. This design put one "Early Bird" in a rather precarious position. He invited a lady for a ride. With side-by-side seating, when he banked in her direction, she nudged him right back and it almost developed into the briefest of romances!

Being seasoned by many years of flying (not fifty, though) I have been completely brainwashed to move the rudder through foot-driven rudder pedals and the ailerons by use of a control wheel. To prevent my being frustrated if I got into a spin, we designed the replica A-1 with a conventional control system. It was also beefed-up in certain areas over the original design load factor of 0.5*g*. The bamboo tail booms were replaced by aluminum tubing. No one knew how to run a stress analysis on a bamboo knot.

When the design work on the A-1 was nearing completion, construction was begun in earnest (Fig. 3). Parts began to take shape in garages and home shops all over San Diego. Even the wives wanted to get in the act and helped fabricate wing ribs, sanded parts, etc. The IAS motto soon became "Glue, man, glue!"

The need for a central facility for final assembly of wing panels and finishing of completed parts was satisfied through the generosity of the San Diego Marines and the use of their hobby shop. Schedules were tough to meet with volunteer labor and there were many anxious moments. As Wenzel put it, "No boss has probably ever been told before, 'But my wife wouldn't let me out!' as a reason for failure to meet schedules." During one crisis, a special two-shift, seven-days-a-week task force was organized under the foremanship of Captain Antoniak, a past Chairman of the IAS San Diego Section. After three weeks of this, the program was back on schedule.

(*Continued on page 65*)

Fig. 1. A-1 on beach at San Diego, early 1912.

# A Political Economist Views

Oskar Morgenstern

*Princeton University*

The author held a Laura Spellman Rockefeller Memorial Fellowship from 1925 to 1928 for study at the universities of London, Columbia, Harvard, Paris, and Rome; and from 1929 to 1938 he taught political economy at the University of Vienna. Since 1940 he has been collaborator at the National Bureau of Economic Research of New York City, and at present is Class of 1913 Professor of Political Economy at Princeton University and Director of the Econometric Research Program. He is author with John von Neumann of *The Theory of Games and Economic Behavior* (3rd Edition, Princeton University Press, 1953), which develops a theory of optimal strategies applicable to economics as well as the military. From 1954 he has been coeditor of the *Naval Research Logistics Quarterly*. Dr. Morgenstern's latest work is *The Question of National Defense* (Random House, 1959; 2nd Revised Edition, 1961). Dr. Morgenstern has at various times been a consultant to the White House, the Atomic Energy Commission, the Joint Commission on Atomic Energy, etc.

WE HAVE DISCOVERED HERE how many g's an individual can stand, but it doesn't seem to have been determined how many lectures an audience can stand. I shall try not to give a lecture, but instead shall make some comments on the preceding papers while wondering whether I have been placed in this position by a friend or an enemy. There is, of course, a great difference between appearing before a University audience to comment on seminar lectures, and standing here—confronted by the highest officers in the Navy and by experts in fields in which I am not an expert. I will try, however, to say what has occurred to me.

Among the many speakers there has been an attempt to look forward to the next ten to fifteen years, but only a few have cast their eyes further, although all were asked to do so. And nobody has looked back fifty years in order to discover what has happened in those fifty years which really brought such tremendous changes. The question is whether one could infer from looking back whether to expect similar changes in the future and what their significance might be. Now, clearly, there is atomic energy and there is the electronic computer probably not much behind it in importance. There is the discovery and development of plastics, and there is solid-state electronics. Naturally there are others, and very important ones, but those mentioned seem to be among the most significant. None is near the end of its facilities and capabilities. Now a few years ago, a national periodical made a survey and asked a number of important scientists what they thought the future would bring. There were all sorts of answers; one which comes to mind is that we would control fusion power and would therefore have unlimited energy at our disposal. Someone else said we would find a cure for cancer, and so on. Also among those questioned was the Vice President of Finance of the Bell Telephone System. And he really knew what he was talking about, what he wanted: he said he hoped that in the next fifty years we would have an absolutely safe and fast method for making out telephone bills. He knew what was necessary, and I have a bitter feeling that some of the projections made here have been similar to such safe and secure matters as the rapid compiling and computing of future telephone bills.

With respect to the spotting of new ideas, it is not just a question of anticipating what may be found—like photosynthesis, for example, or the discovery and understanding of how our brain really functions and how we can translate this understanding into superior computers of a kind totally different in their capabilities from our present computers. There is also another problem—namely, the problem of spotting ideas which are already here and which are not being recognized and utilized. There are many illustrations of this, but I will give only two.

DDT, for example, was in existence some 30 to 40

# The Navy/Industry Look at the Future*

*Overconfidence and traditional thinking are barriers to progress in our society, especially vis-à-vis the Soviet bloc. Both dangers are discussed in the light of advancing technology, and the necessity of "liberating our minds from our daily thinking" if we are to survive is pointed out.*

years, if I recall correctly, before its present use was discovered. And the theory of the thermocouple has been well known for decades, although the device is only now coming into use, with great consequences and important results. The problem, therefore, is how to liberate our minds from our daily thinking. Can we do it? Can we invent something so that we really recognize a new idea when it comes and can introduce it quickly into our life? This is not an easy thing. I wish someone would make an effort; the Office of Naval Research—which supports in such admirable manner so many very valuable projects—might perhaps be induced to support efforts to discover how one can invent new methods.

This is somewhat similar to the idea which the great philosopher Leibnitz had, when he said we ought eventually to discover what he called *Mathesis universalis*—that is to say, a method with which to derive true theorems. Such a method for finding true theorems, if we had it, would really produce true progress in mathematics. Well, maybe we can find a method to recognize and then perhaps to develop new thoughts, also in the fields under discussion at this symposium. To illustrate the difficulty of doing this, let us merely look at a few predictions which have been made—or, rather, have *not* been made. Who predicted—let us say in 1910, '20, '30, '40, or even in 1950—the Polaris missile? Something exceptional and discontinuous happened. Vannevar Bush, certainly a man of great authority and one who was importantly connected with the Manhattan project, stated—I think in 1948—that there could not be an ICBM. The great English chemist Haldane said in the '20's that it was well-nigh impossible that atomic energy could ever be used for anything. In 1947, a very good Austrian physicist named Thirring published a book in which the entire scheme of the atom bomb was laid down—although in Austria the author was completely divorced from all the information we possessed about the atomic bomb, and the book was based on the mere fact that an explosion had taken place. But the same man said in 1936 that there could be no space flight. It seems, therefore, that there is a great danger in the extrapolation of present technology. The very uncertainty of the future makes it dangerous to predict on the basis of the current, because although we can predict somewhat on current lines, another technology can come a little bit later and overtake the current one completely—and I think this may still have to be expected.

How does one break with tradition? In 1940, in the same month in which the mechanized armies of Hitler were overrunning western Europe, there were hearings before the Military Affairs Committee in which the Army appeared and insisted that the horse cavalry was superior to the tanks which were at that time already operating under combat conditions. It is worth while reading these statements, for they may give us the idea that we could be in the same boat and may have similar backward ideas. We cannot, however, recognize them as quickly as the absurdity of arguing in favor of horse cavalry was recognized in 1940. (*Continued on page 47*)

* **A title chosen by the Editors, who also have endeavored to leave in this published version of Dr. Morgenstern's IAS/Navy Naval Aviation Meeting address expressions which, when spoken, were applauded enthusiastically.**

# Short-Haul Air Transportation

William P. Kennedy, MIAS

*Lockheed Aircraft Corporation*

THE SHORT-HAUL SECTOR of air transportation presents an intriguing and challenging problem from both a marketing and a technical point of view. The total short-haul market is impressive by any measure—numbers of airplanes, numbers of passengers, or numbers of flights. Unfortunately, however, it is quite diverse in character, depending on the size of the communities being served.

More of the traveler's time on a short-haul trip may be spent on the ground than in the air, so several technical areas—not just aircraft design—are involved in the short-haul transportation problem.

Also, since surface transportation and airport terminals should be optimized for short-haul transportation, local airport and transportation agencies will undoubtedly play an important role in smoothing the way for the short-haul traveler in the future. Coordination of activities of the several groups involved will call for good organization and capable administration, and a "system" approach to the whole short-haul problem.

Mr. Kennedy received his B.S. in aeronautical engineering from the University of Michigan in 1935 and his Master's degree from the Massachusetts Institute of Technology in 1936. He worked in preliminary design, aerodynamics, and structures at Martin's until 1939, and at Curtiss-Wright's Airplane Division served as Assistant Contract Manager (Buffalo) and Assistant to the General Manager (Columbus) from 1939 to 1945. Following this, he was a sales engineer for Boeing, and an aerodynamicist and design engineer for Willys Overland and General Tires' Rocket Division. Since early 1949, Mr. Kennedy has been at Lockheed in sales and marketing, and at present is Assistant Director of Market Research.

## Market Characteristics

One of the most important centers of short-haul air transportation is located in the Northeast section of the United States where a large number of good-sized, highly industrialized cities are spaced quite close together (Fig. 1). It will be noted that the most heavily traveled flight segments appear to fan out from the major centers, Chicago and New York. Each of these might be considered the center of a "radial" system. In the overall concept of air transportation, one might envision the long- and medium-haul aircraft—large, fast machines, operating between major population and business centers—and the short-haul air vehicles operating from these large cities "radially" out to and back from smaller cities, such as those shown. In most instances the flights will not simply be shuttles from the large city to the small city and return, but will extend to several other points to serve a considerable area by nonstop and skip-stop flights concentrated in the busy hours of the day and multistop flights scheduled during the less busy hours. For instance, an early morning flight might be scheduled from *each* of Buffalo, Rochester, and Syracuse—to New York—but a later flight might be routed from Buffalo to Rochester to Syracuse to New York.

It will be noted that many of the flight distances between the cities (Fig. 1) are in the area of 200 statute miles, which means that many of these flights might be accomplished by a suitable vehicle in considerably less than one hour.

The foregoing concept of a short-haul system does not include flights from one airport to another within a metropolitan area or from the suburban community to downtown. At present, this type of service is being supplied by helicopters. The distances are in the 10- to 20-mile range for the most part, and the service might be described as "very

*"The question really rests with the community, which should adapt its airport and terminal facilities so that maximum benefits can be realized from use of VTOL machines. This applies specifically and most importantly to the large cities from which 'radial' service emanates"*

short haul" or "metropolitan area" air transportation to differentiate it from "short haul."

Since airplanes provide the greatest timesaving to travelers on long- and medium-haul flights, there has been a concentration of effort by aircraft manufacturers and air carriers on these sectors of air transportation. However, a large portion of traffic is concentrated in the short-haul end of the business. Data from timetables indicating the seat-miles supplied in the United States on flight segments less than 1,000 miles in length show that this category represents more than 70 percent of the total U.S. supply of air transportation (Fig. 2). Furthermore, one can see by the height of the bars between 100 and 300 statute miles that the heavy concentration of seat-mile supply is on these short-haul segments.

Another pertinent factor in the short-haul market relates to penetration. On long-haul trips the airplane has displaced the railroad train as the important vehicle for carrying passengers. However, on short trips, air vehicles provide a relatively small portion of the total intercity transportation service. Thus, air transports are in a competitive situation, and in a position, if they provide improved service, to take over a considerable amount of traffic from railroads, bus lines, and private automobiles.

In view of the high level of short-haul traffic which exists now and the possibility of deeper penetration into the total short-haul market, it is not difficult to anticipate that more airplanes, (*Continued on page 72*)

**Fig. 1. Heavily traveled short-haul flight segments (under 300 statute miles) in the New York-Washington-Chicago area.**

# Gas-Floated Spinning Spheres

J. H. Laub • H. D. McGinness, MIAS

*Jet Propulsion Laboratory, California Institute of Technology*

STATIC PERFORMANCE characteristics of spherical bearings under load, lubricated by a compressible fluid, were investigated both analytically and experimentally in a previous paper.[1] Since gas-supported spheres are not only very useful as stationary pivots with three degrees of freedom but are also of considerable interest to inertial guidance and control devices, the investigation has been extended to gas-floated spinning spheres. Two applications might be mentioned here—namely, the use of a gas-floated spinning sphere for momentum transfer in the attitude control of space vehicles, and the use of a rotating free sphere as a stable reference in inertial instrumentation.

### Spinning Sphere Within a Concentric Shell

In applications of this kind a spinning sphere, which may be hollow or solid, is supported either within a hollow concentric shell (Fig. 1) or by a number of pressure pads which are supplied with a compressed gas (Fig. 2). In the case of a stationary shell surrounding the spinning sphere of radius $R$ and spaced a very small distance $h$ from it (Fig. 1), the sphere is subject to a viscous drag torque $T$ in a gas of absolute viscosity $\mu$. The total torque $T$ can be found by integrating the drag torques $dT$ of elementary spherical segments over the surface of the sphere, as indicated in Fig. 1. The radius of an elementary segment at angle $\theta$ is $R \sin \theta$; its drag surface area is $2\pi R^2 \sin \theta \, d\theta$, and its peripheral velocity is $\omega R \sin \theta$, where $\omega$ is the angular velocity of spin. The differential torque is given by the following equation:

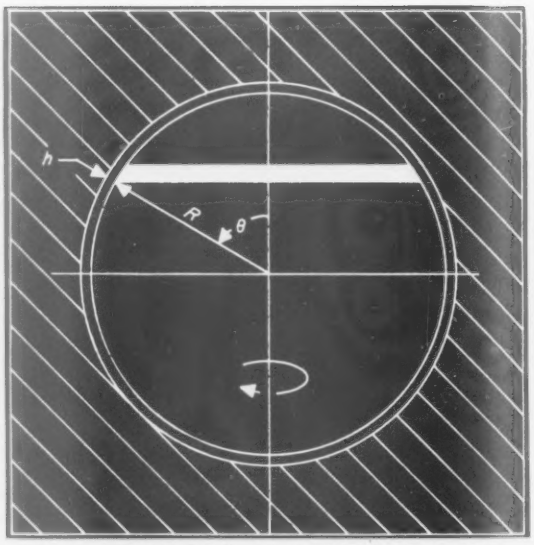



Fig. 1. Spinning sphere in hollow shell.

$$dT = \frac{\mu}{h} \overbrace{R\omega \sin\theta}^{\text{Velocity}} \overbrace{R \sin\theta}^{\text{Moment Arm}} \overbrace{2\pi R^2 \sin\theta \, d\theta}^{\text{Surface Area}} = \frac{2\pi\mu\omega R^4}{h} \sin^3\theta \, d\theta \quad (1)$$

The total drag torque is found by integration:

$$T = \frac{2\pi\mu\omega R^4}{h} \int_0^\pi \sin^3\theta \, d\theta = \frac{2\pi\mu\omega R^4}{h} \left[ -\frac{1}{3} \cos\theta \, (\sin^2\theta + 2) \right]_0^\pi = \frac{8\pi\mu\omega R^4}{3h} \quad (2)$$

The work described in this paper was performed at the Jet Propulsion Lab. for NASA under Contract No. NASw-6.

- *Spinning masses of spherical configuration, supported by compressed gas, offer considerable interest to inertial guidance and control techniques.*
- *Typical applications involve stable gyro references and momentum-transfer devices for spacecraft-attitude control.*
- *The viscous drag and power requirement of gas-floated spheres spinning within a concentric hollow shell and within a multiple-pad system are analyzed as functions of rotational velocity, sphere diameter, spin-axis direction, and gas characteristics.*


The power $P$ required to maintain a spin velocity $\omega$ is

$$P = \omega T = 8\pi\mu\omega^2 R^4/3h \qquad (3)$$

It will be noted that the drag torque $T$ and the power $P$, required to maintain a given spin velocity, both vary with the fourth power of the sphere radius $R$. An example will illustrate the order of magnitude of $T$ and $P$ (Fig. 3): A sphere of 2-in. diameter ($R$ = 1 in.), rotating at 5,000 rpm in air at room temperature ($\mu = 26 \times 10^{-10}$ lb-sec/in.$^2$) inside a hollow shell uniformly spaced 0.003 in. from the sphere, will require 0.266 w to overcome a friction torque of 4.39 g cm. If the sphere is spun at $N$ = 40,000 rpm, the corresponding values are $T$ = 35.12 g cm and $P$ = 14.5 w.

## Spinning Sphere Supported by Pads

Actually, a spinning sphere can be completely contained and supported by four or more pads of small area instead of a complete shell. This will substantially reduce the drag and power requirement. The contribution of each pad to the total drag torque depends on its location relative to the spin axis; it will be a minimum if the spin axis goes through the pad center and a maximum if it is located on (straddling) the equator.

The range within which the drag torque of an individual pad will vary is shown by the following analyses of the minimum and maximum in these two extreme positions of a pad.

### *Minimum Drag*

If a circular pad is centered on the spin axis and extends over an angle $\sigma$ (Fig. 4a), integration of Eq. (1) gives for its drag torque:

$$T = (2\pi\mu\omega R^4/h)\int_0^{\sigma/2} \sin^3\theta\, d\theta$$
$$= (2\pi\mu\omega R^4/3h)\{2 - [2 + \sin^2(\sigma/2)]\cos(\sigma/2)\} \qquad (4)$$

As an example, if

$$\sigma/2 = 30°,\ T = 0.108(\mu\omega R^4/h)$$

### *Maximum Drag*

An approximation of the drag torque of a small circular pad straddling the equator (Fig. 4b) is obtained by calculating the (*Continued on page 75*)

Dr. Laub is Chief, Guidance and Control Research, Jet Propulsion Lab., C.I.T., having begun a distinguished career as a researcher in the Engineering Labs. of AEG (German General Electric Co.), Berlin. From 1927 to 1930, he was Asst. Prof. of Electrical Engineering at the Institute of Technology, Stuttgart, and was Manager of the Electronics Labs., Research Institute of AEG, from 1930 to 1933. From 1935 to 1950, he served as General Manager of Hanovia Co. and Charles Englehard, Inc., becoming Executive Vice-President of Englehard Industries in the latter year. His association with C.I.T. began in 1957 following a 4-year period as a Management Consultant. Dr. Laub is the author of more than a score of technical papers.

Mr. McGinness is a Research Specialist, Guidance and Control Research, Jet Propulsion Lab., C.I.T. A Registered Mechanical Engineer in California, he was graduated from Parks College of St. Louis University with a B.S. degree in aeronautical engineering, then did graduate work at the University of Southern California. For 20 years, beginning in 1940, Mr. McGinness worked exclusively in design—first with Lockheed, then as Senior Design Engineer at the Southern California Cooperative Wind Tunnel. His present position dates from last year.

# Control of Ground Effect Machines

## *Preliminary Analysis*

David A. Lieberman • Peter G. Fielding, AFIAS • William J. Neff, AIAS

*Booz • Allen Applied Research, Inc.*

THE GROUND EFFECT MACHINE (GEM) presents an interesting problem to the control engineer. It is essentially a vehicle which is supported by an air bubble. Its orientation with respect to the earth is not readily defined as it is, for example, with autos and ships. The inherent stability of the GEM and the related question of its control are clearly connected to the mechanics of this air cushion.

It has become apparent that control problems are one of the major obstacles preventing GEM's from achieving their full potential. Much work is in progress to define and overcome these problems. As is usual, the first step is to describe the equations of motion of the process to be controlled. Then suitable control schemes can be developed and optimized.

This article describes the GEM as a physical process and then develops the generalized equations of motion. From these equations, conclusions regarding control effects are drawn, and comparisons are made with experimental results.

### Support by Ground Effect

The ground effect machine may be defined as a machine operating in the realm between surface-limited and dynamic-lift vehicles, in close proximity to the surface, being separated from it by a cushion of air.

By virtue of its freedom from surface limitations and the almost frictionless cushion of air required for support, the vehicle requires a low order of motive power. In this respect, forward speed is limited by the combination of parasitic and frictional forces together with the momentum drag associated with the lift forces.

Vehicles based on this principle have been under development for more than 30 years. During the last 5 years, the rate of development has greatly increased.

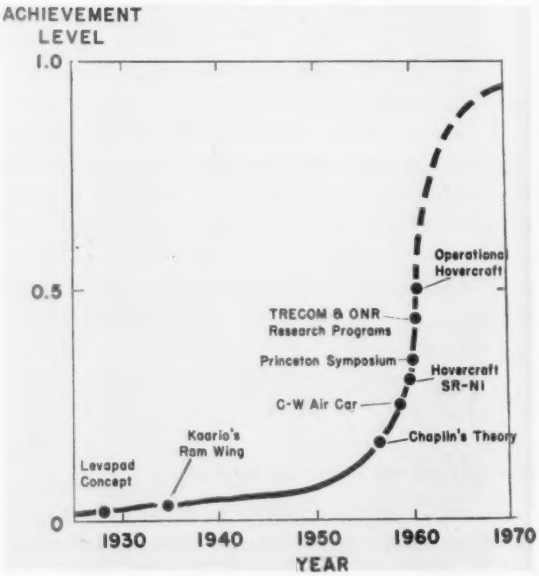



Fig. 1. Historical development of GEM's. (From Ref. 2)

A pictorial representation of this activity is given in Fig. 1. The ordinate is a subjective achievement level, which may be closely linked with an effort level. In 1928, Dr. Andrew Kucher of the Ford Motor Company started his work on the levapad principle, and in 1935 Toivo Kaario built a model ram-wing sled in Finland. These programs and others were carried on at a slow pace until the mid-1950's. At this point, there was an acceleration in the rate of development. This acceleration was

*An article prepared especially for engineers not intimately acquainted with control theory, thus avoiding a detailed exploration of current equations and theories. The physical process of the GEM is described and generalized equations of motion developed.*

marked by the test work begun in England by Christopher Cockerell, and by the appearance of a firm theoretical basis for the annular jet machine. This theory, developed in 1957 by Harvey Chaplin of the David Taylor Model Basin, is considered an important background reference for all succeeding work in the field.

In 1958 and 1959, the first test vehicles appeared, both in this country and abroad, among them the Curtiss-Wright Air-Car and the Sanders-Roe Hovercraft. The Princeton Symposium of October 1959 was a milestone in the development of the ground effect machine, since it brought together almost the entire existing state-of-the-art in research, development, and testing.

The methods by which the ground effect principle may be applied to vehicles are divided into three groups, as illustrated in Fig. 2.

The air-leakage machines, represented by the plenum chamber and levapad, are those in which air is pumped through the vehicle and expelled from the perimeter of the base. The plenum-chamber concept has been considered in many of the test vehicles because of the simplicity of construction. The levapad utilizes a much higher air pressure, and depends on viscous mixing of airflow between the vehicle base and the ground surface. It is anticipated that the levapad will be used in configurations with a rail-supported system.

The second class of ground effect vehicles are those using the peripheral seal, and represented by the annular jet and recirculating devices. In these machines, the cushion of air which supports the weight of the vehicle is held by a circular jet around the periphery of the base or (*Continued on page 50*)

Mr. Lieberman received a B.S. degree from the Illinois Institute of Technology and an M.S. from Northwestern University. He has twelve years' industrial experience designing electrical pneumatic and hydraulic control systems, and has conducted product improvement programs in acoustics, instrumentation, electrical appliances, electromechanisms, ball bearings, gyros, and fluid-flow devices. At Booz·Allen, he has developed hydraulic actuation and control systems for high-speed production machinery, evaluated chemical process control schemes, designed nuclear control mechanisms, determined control requirements for military systems, and analyzed the technical and commercial potential of new automotive equipment. Mr. Lieberman has also published seven papers dealing with feedback control problems and automatic control systems. He is a licensed professional engineer, and a member of the ASME and AIEE.

Mr. Fielding, inventor of a jet recirculation system for GEM's and holder of joint patents on a BLC system for the C-130B aircraft, is Project Director of his firm's Transportation Research Office and responsible for work being done for ONR and Army Transportation Corps on the overall GEM program. Associated with some of the major developmental programs in the aviation and aerospace fields for the last 20 years in the U.S. and U.K., his experience covers several first British jet aircraft designs and project coordination duties on the Black Knight re-entry test vehicle. He joined Lockheed's Georgia Division in 1955 and has been associated with Booz·Allen since 1959. He also is an Associate Fellow of the RAeS. *(Brooks photo)*

Mr. Neff received his B.S. and M.S. degrees in aeronautical engineering from the Massachusetts Institute of Technology. His experience has been in the fields of aircraft performance and flight-test and air transport operating problems. As a flight-test engineer for the FAA, he was responsible for the evaluation of performance requirements for jet transport aircraft. He also participated in analysis of airline operational take-off performance. Mr. Neff developed a program for testing flight simulators used in airline training programs. As an officer on active duty with the ARDC, he served as a test project officer for the F89J special weapons installation flight-testing division; he also conducted tests on ground handling equipment and training units associated with this system. In addition, Mr. Neff has been with the Mechanics Div. of the National Bureau of Standards, and with the aerodynamics group of a major aircraft firm. He is a member of the IAS.

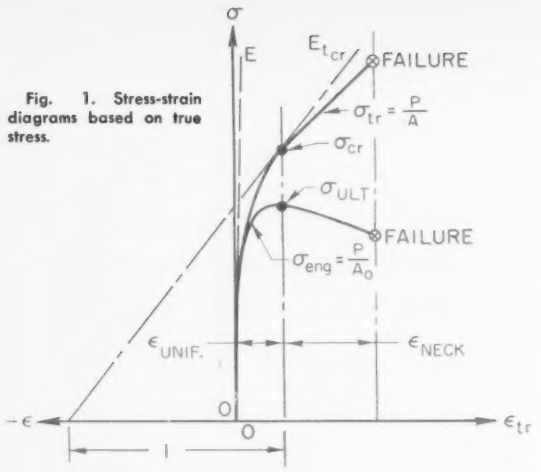



Fig. 1. Stress-strain diagrams based on true stress.

# Tensile Instability

F. R. Shanley, FIAS

*University of California, Los Angeles*

Professor Shanley has been a member of the engineering faculty at U.C.L.A. since leaving Lockheed in 1947. Many of his papers on structures and materials have been published in the IAS *Journal of the Aerospace Sciences*, and he is the author of two textbooks, *Strength of Materials* and *Weight-Strength Analysis of Aircraft Structures*, the latter having also been published in the Soviet Union. After receiving his B.S. in mechanical engineering at Penn State University in 1927, he worked for the newly formed Consolidated Aircraft Company (now Convair) and later for the CAA (now FAA), where he was in charge of structural airworthiness requirements. At Lockheed he was Chief Structures Engineer. He has been a consultant to The RAND Corporation since 1947 and has served on various committees of NASA, the Air Force, Defense Dept., Column Research Council, etc.

MAXIMUM LOAD-CARRYING capacity of a material in pure tension is represented by the "engineering" *ultimate tensile stress* (maximum load divided by original cross-sectional area). For brittle materials this stress corresponds with actual failure (separation), but for ductile materials actual failure does not occur until after the load has reached this maximum and has decreased, sometimes to a much lower value. For present purposes a ductile material will be defined in this manner—i.e., a material for which the ultimate tensile loading capacity is *not* governed by actual failure (separation).

The conventional tension test gives the value of the ultimate tensile stress directly, for simple tension. In predicting behavior under other types of loading, such as biaxial tension, shear, etc., it is necessary to convert the nominal tensile stress into *true* stress, defined as tensile force divided by actual (instantaneous) area. The word *true* is italicized here because after necking begins this stress represents an average for a nonuniform stress over the cross section, as has been shown by Nadai,[1] Bridgman,[2] and many others. For convenience, the italics will be dropped hereafter.

Two different definitions of strain are in common use. The engineer who wishes to predict the extension of a member loaded in tension uses "engineering" strain, which is defined as change of length divided by *original* length. True strain is defined by dividing a strain increment by the actual (instantaneous) length. These definitions are summarized below.

$P$ = tension load

The author wishes to express his appreciation to The RAND Corporation for its support of this investigation.

$A_0$ = original (unloaded) cross-sectional area
$A$ = actual (loaded) cross-sectional area
$L_0$ = original (unloaded) length
$L$ = actual (loaded) length

$$\sigma_{eng} = P/A_0 \tag{1}$$

$$\sigma_{tr} = P/A \tag{2}$$

$$\epsilon_{eng} = (L - L_0)/L = \Delta L/L_0 \tag{3}$$

$$d\epsilon_{tr} = dL/L \tag{4}$$

$$\epsilon_{tr} = \int_{L_0}^{L} dL/L = ln\ (L/L_0) \tag{5}$$

An equivalent definition of true strain can be obtained by neglecting elastic strains (usually very small in comparison with plastic strains, for ductile material). Since plastic straining does not cause change in volume we may write

$$dV = A\,dL + L\,dA = 0$$

from which $dL/L = -(dA/A)$

# (Necking) of Ductile Materials

*The relationship between ultimate tensile strength and uniform elongation is investigated. It is shown that attainment of the maximum load does not necessarily coincide with the beginning of tensile instability. A theory of necking, based on a linear relationship between average true stress and true strain, is proposed. Neck development is analyzed from the phenomenological viewpoint. Methods of achieving higher ultimate tensile strength without reduction of uniform elongation are discussed.*

or

$$d\epsilon_{tr} = -(dA/A) \tag{4a}$$

Substituting this in Eq. (5) and integrating gives

$$\epsilon_{tr} = ln\ (A_0/A) \tag{6}$$

This definition of strain is particularly useful in dealing with the necking phenomenon. The use of area as a basis amounts to working with an indefinitely small gage length.

For conversions from one system to another the following relationships may be easily derived.

$$\epsilon_{tr} = ln\ (1 + \epsilon_{eng}) \tag{7}$$

$$\sigma_{tr} = \sigma_{eng}(1 + \epsilon_{eng}) = \sigma_{eng}e^{\epsilon_{tr}} \tag{8}$$

Figs. 1 and 2 show these relationships in the form of stress-strain diagrams (elastic strains have been exaggerated for clarity).

If the true-stress true-strain diagram is known, we can determine the slope at which the load will be a maximum. (This procedure originated with Considère; see Ref. 1, p. 71.)

By definition,

$$P = \sigma_{tr}A$$

For maximum load

$$dP = 0$$

Then

$$dP = \sigma_{tr}dA + A\ d\ \sigma_{tr} = 0$$

$$d\sigma_{tr} = -\sigma_{tr}(dA/A)$$

Utilizing Eq. (4a), we obtain

$$d\sigma_{tr}/d\epsilon_{tr} = \sigma_{tr} \tag{9}$$

This states that the load, and consequently the engineering stress, will be a maximum when the slope of the true-stress true-strain diagram is equal to the true stress.

For convenience we shall designate the slope by the tangent modulus symbol, $E_t$ (as in column theory).

The condition for maximum load will be designated "critical." Then

$$E_{t_{cr}} = (d\sigma_{tr}/d\epsilon_{tr})_{cr} = \sigma_{cr} \tag{10}$$

The value of $\sigma_{cr}$ can be located graphically as shown in Fig. 1, in which true stress is plotted against true strain.

By using the substitutions of Eqs. (7) and (8) the critical slope can be found in terms of true stress and engineering strain. (*Continued on page 55*)

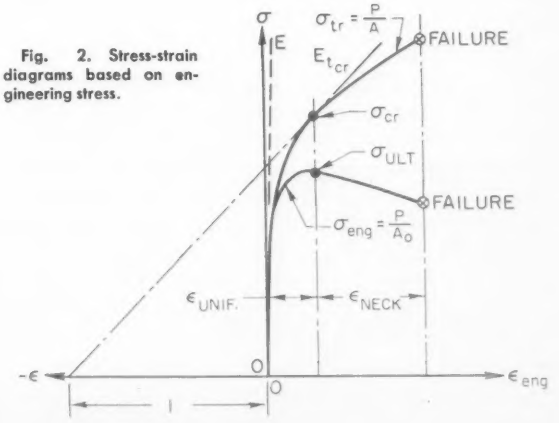



**Fig. 2. Stress-strain diagrams based on engineering stress.**

# Twenty Times Better

Harry Weitz

The author is a Senior Engineer in the Inertial Guidance Department of Arma Division, American Bosch Arma Corp., and now concerned with the entire gamut of developments making up ultra-precise inertial guidance components. His 17 years of electromechanical engineering experience have included design of tiny servo motors as well as huge precision structures such as described in his personal adventure in engineering—the accompanying report.

ENGINEERS probably will agree to a man that the wealth of meaning behind a well-used and sometimes abused adjective has started them off on an unforgettable adventure in engineering. The word? "Impossible!" This contributor has a case in point.

It all began when Arma was awarded a contract for an inertial guidance system. Not the least of many problems posed by this economically healthy event was how to simulate high $g$ acceleration profiles to an accuracy of several parts in a million—necessary to laboratory test and calibrate any extremely accurate inertial guidance system. What it meant was that we had to find a centrifuge machine at least 20 times better than any extant. The stark fact soon became apparent that, if we were to get it, we'd have to build it—and this is where the writer entered the picture, with responsibility for getting the job done.

The design of such a machine necessitated advancement in several specialty fields, including bearings, motor design, and structures, as well as significant improvements in other fields including electronics, metrology, hydraulics and air conditioning. Altogether, these factors posed a formidable problem when coupled with tight research and delivery schedules.

After initiating a research and development program to prove the feasibility of several proposals, construction was begun. The basic machine consisted of a built-up, truss-type rotating arm whose nominal effective radius was 100 in. The writer decided to use one end of the arm for "precision" measurements up to 15$g$ and the other end for environmental testing of packages up to 25$g$. We recognized that temperature control of the machine and its parts was of extreme importance and calculations confirmed this. The problem was solved by locating the machine inside a steel silo-like structure with a smooth, aluminum inner shell. Space between the steel and aluminum walls was air conditioned, thus maintaining temperature of the huge structure (55 tons) to $\pm 2°$F. For measuring the static length of the centrifuge arm, two 1-in. diameter quartz rods were used after being calibrated by the Bureau of Standards to 200 millionths of an inch. Since it was calculated the amount the arm would stretch under dynamic conditions, a super micrometer was installed which extended through the centrifuge enclosure and contacted the rotating arm. After initially zeroing the arm length using the super micrometer, it was a simple matter to measure the amount the arm had stretched while rotating. This $\Delta r$ we added to the static length of the arm measured with the quartz rod to obtain $R$ in the equation $A = RW^2$. The measurement and control of $W$ is covered further on.

Very early in the project analysis, we recognized that the arm drive could not be belt or gear driven and conventional ball bearings could not be used. We had but one alternative—direct drive using fluid bearings. The problem of driving a load directly and synchronously between 5 and 100 rpm with a velocity stability of 1 part in 200,000 was a fascinating engineering task.

The drive system consisted of three main elements: a 3-phase frequency power supply, three rotary amplifiers, and an 8-pole, 3-phase synchronous motor.

Included in the power supply were three power amplifiers with preamps, coupling circuits, and a 3-phase variable frequency oscillator. For an 8-pole synchronous motor to be driven at speeds of 5 to 100 rpm, the oscillator must vary from 0.5 to 6.5 cps. The stability problem became very clear to us: to minimize the oscillator temperature drift, we buried the entire oscillator assembly in the concrete base of the centrifuge. The 3-phase output of the oscillator is fed to three power amplifiers. Voltage output of the amplifiers was designed to be auto-

(*Continued on page 80*)

# LETTERS to the Editor

## A Letter *From* the Editor

ABOUT THE MOST REWARDING thing that can happen to a magazine vitally interested in its readers is to hear from them—often and loud. There just isn't a substitute for *Letters to the Editor*! Letters give guidance to an Editor's intuition born of experience. They help place value upon ideas emanating from an endless variety of sources. They also provide indisputable proof that a publication is being read (which every Editor has to know) and constitute a barometer indicating how healthy interest and growth may be cultivated and maintained.

When reader reaction turns into a tide of opinion, events occur (or should) as rapidly as wheels can be made to turn. Such an event is the subject of this letter **from** the Editor, so without further preamble we can report that beginning with the January issue as many articles as possible—consistent with sound economical publishing practices—will appear on consecutive pages.

This will be pleasant-tasting news to hundreds of our readers who reacted to a letter by W. L. Gray, MIAS, protesting in our August issue against the "fragmenting" of articles.

While it would be impossible to publish all letters which precipitated this format change, pertinent excerpts from some follow:

■ "We hope you will give serious consideration to Reader Gray's first two comments; we heartily concur." —**D. E. Ordway** and **M. M. Sluyter,** MIAS, and **J. P. Moran** and **G. R. Hough,** AIAS (Therm Inc.).

"The piecing together of articles and gluing onto paper for a coherent reference requires more effort than I care to invest most of the time." —**L. R. Parkinson,** AFIAS.

"Recognizing that advertisers must be served, I feel that much could be done along the lines suggested by Mr. Gray to facilitate reading and clipping of articles." —**J. L. McKelvie,** MIAS (The Bendix Corp.).

"I most heartily agree with W. L. Gray in the August issue." —**R. R. Dieckmann,** MIAS.

"Aerospace Engineers must keep up with their field by reading significant material such as is found in AEROSPACE ENGINEERING. Equally important, however, is the reading convenience and 'file-ability' of individual articles. I urge you to change the inside format accordingly." —**Walter Unterberg,** A.E. subscriber.

"If you change, you'll be in good company." —**Douglas A. Heydon,** MIAS (Space Technology Labs.).

"Even with copying equipment, obtaining a copy of a given article in its present scattered distribution is not only difficult but frustrating." —**E. E. Sechler,** FIAS (Professor of Aeronautics, Guggenheim Aeronautical Laboratory, California Institute of Technology).

"Keep articles integrated for easier reading, filing, and information retrieval." —**Karl L. Sanders,** MIAS (Norair Div., Northrop Corp.).

"'Dismantleability' entails a few blank pages and a few holes, and is therefore more expensive than the conventional form of assembly, but we believe that the small extra cost is worth it, if it results in a generally more useful publication." —**H. C. Luttman,** FCAI, AFIAS (Secretary, CAI, in discussing the CAI *Journal*).

"I concur fully with the recommendations of W. L. Gray." —**H. E. Weihmiller,** AFIAS.

"It (continuity of articles) would be a great asset to those of us desiring to seriously read and file such articles." —**Lt. Col. John W. Bennett, USAF,** MIAS.

"I think they (the articles) are good too. I don't save all, but I wish I could remove the ones I want and wind up with one integral piece that is minimum in size and continuous." —**H. W. Smith,** MIAS.

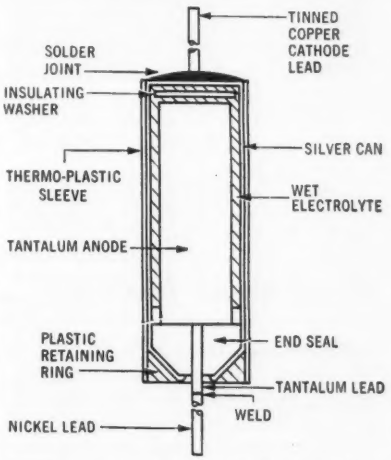
"I vote for non-fragmentation . . . split articles are irritating in a popular magazine and inexcusable in a technical magazine." —**L. Joseph Herrig,** MIAS.

"Keep each article together, separated by at least one page of ads or blank paper. (You are wasting enough space now in pretty stuff to provide the blank paper, so don't say you can't afford it.) An article worth studying is worth saving, but the whole magazine isn't. Remember, it is impossible to read a technical article; it has to be studied. Therefore, you are not competing with the


# NEW STRAIGHT WALL TANTALUM CAPACITOR CAN'T LEAK

**Meets MIL C 3965-B, Style CL-64, CL-65.**

A new space-saving approach to the design of wet tantalum capacitors ends mounting problems encountered with flanged types and yet will not leak.




ITT's compact, sintered slug tantalum capacitor features a wedge-shaped seal held under compression by an epoxy retainer ring formulated for thermal characteristics inverse to those of silver. Ordinary, straight-wall capacitors leak along the lead when elastomer compression is reduced as the silver can expands. Not so with the new ITT design!

This new, compact capacitor conforms to specifications MIL C 3965-B, Style CL-64, CL-65 and provides both the compactness and rugged reliability required in missile, airborne and mobile equipment. For details, write today requesting Bulletin No. 610.

ITT

**CAPACITOR DEPARTMENT**
COMPONENTS DIVISION
INTERNATIONAL TELEPHONE AND TELEGRAPH CORPORATION, PALO ALTO, CALIFORNIA

*Ladies' Home Journal*." —**Gifford Bull,** MIAS.

"Place your table of contents right on the title page . . . it's more important than a pretty picture . . . why not have the ads . . . inserted between the cover and the technical articles. You could then number the pages of the technical articles consecutively for each volume starting with January." —**G. E. Halpern** (Chief, Libraries, The Martin Co.).

"I have no comment other than to praise the technical articles themselves, but have always considered the splitting of papers, 'Continued on Page . . .' to be a great defect in presentation." —**J. R. Anderson,** AFIAS, AFRAeS (Warwickshire, England).

"Let us hope that the correspondence received by the IAS in the near future will establish whether there is indeed a sharp difference of opinion among readers . . ." —**W. L. Gray,** MIAS (Responding to his copy of the Luttman letter).

"Mr. Gray's letter against 'fragmentation' has my wholehearted support." —**L. S. Dzung,** MIAS (Baden, Switzerland).

"May I express my wholehearted agreement with the remarks of Mr. Gray." —**J. N. Ball,** AFIAS.

"I agree with Reader Gray . . . 'an orderly presentation shows an orderly mind.'" —**W. Socha** (Montreal Reader—Canada).

"I vote for this." —**W. E. Roberts,** MIAS (Checking Reader Gray's Points 2 and 3, and following paragraph, on Page 95 of the August issue).

"The practice of spreading articles all over the magazine is exceedingly frustrating to one who likes to clip material for file purposes." —**E. O. Doebelin,** AIAS (The Ohio State University).

" . . . continuity of individual articles is the hallmark of a professional society's publication. Having to hunt for the 'continued-on' page hampers serious reading, and tends to stop one cold when reading over lightly. Let's keep the articles continuous." —**Douglas A. King,** MIAS.

✦ ✦ ✦

## Naval Attack Aviation (*Continued from page 11*)

multiple-bomb racks. Each station, incidentally, is carrying six 500-lb bombs, while the outboard stations are carrying Bullpups. This multiple-bomb carrying scheme vastly increases the usefulness of any naval attack aircraft in a limited-war environment.

Thus far we have discussed the most sophisticated system for the most demanding limited-war situations. In the dual interest of overall cost (Fig. 4) and the maintenance of fleet capability all over the world, it is unreasonable to expect that *all* of the Navy's attack aircraft will involve this degree of electronic sophistication. The important consideration, however, is that at least *some* of the Navy's aircraft will have *all* of this accuracy and all-weather capability. All of them can profitably use the range and payload capability of such aircraft. It is, therefore, safe to assume that eventually the same airframe will be used with and without the added cost of the electronics. In large-scale production, these electronics represent over 50 percent of the cost of the total system.

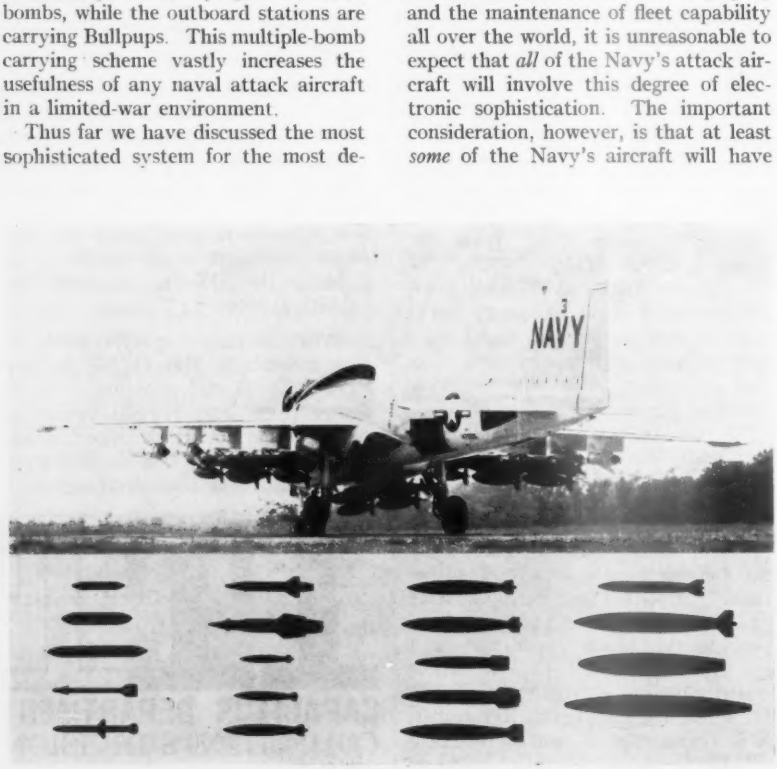



Fig. 3. Weaponry, 1965.

From this point of departure, representing the 1965 state of the art in fleet attack systems, let us look at the directions that progress may take in the next 10 years. We may consider three elements whose characteristics determine the overall effectiveness of the attack system—the basic airframe, the electronic complement, and the weapon complement.

The first and most important basic airframe development concerns the replacement by turbofan engines of the straight turbojets used in all of the Navy's current attack aircraft (Fig. 5).

The take-off weight of today's all-weather naval attack aircraft, on a typical 600-mile-radius mission, can be divided into the following approximate percentages: About 58 percent of the gross is evenly divided between fuel and weapons, 27 percent is in structure and mechanical devices, close to 10 percent in the propulsion system, and the electronic complement, including communications gear, is about 5 percent. Conversion to turbofan propulsion (Fig. 6), which can be accomplished in the immediate future, will maintain the same overall percentage for the propulsion system, but will provide either a 25 percent increase in range for the same payload or, probably more important, will permit a 25 percent increase in payload for the same range. No crystal ball is required to foresee that this will be adopted as soon as available.

Equally plausible for this later time period is an attack aircraft with at least three times the speed of the A2F. This should not be greeted with surprise since it would have been possible to make the A2F Mach 2+ at the expense of its other important characteristics. Actually, total productivity in weapons-delivered-per-hour may be more important in the limited-war attack context than speed *per se*. It is pretty well agreed that speed alone is not the answer to survival in the age of missile defenses (Fig. 7).

We believe, therefore, that supersonic attack aircraft for limited-war applications will be accepted only when their productivity actually exceeds that of subsonic machines. The advent of non-afterburning turbojets in a Mach 3+ attack aircraft now makes it appear that eventually this higher productivity can be attained, but only at the expense of a substantially higher-priced machine. In

this case, the new proportions by weight would compare with today's aircraft as shown in Fig. 7: Fuel load increases to 36 percent of gross, structural weight increases to 36 percent of gross, propulsion to 14 percent of gross, while weapon load reduces to approximately one third.

Another possibility which is beginning to receive widespread attention is the capability of achieving supersonic speeds at sea level, through the use of variable sweep wings (Fig. 8), to permit extended subsonic operation rather than the Mach 3 all-the-way performance of previous aircraft. In this attack system, the propulsion percentage is still about 14, while fuel weight has been replaced by structural weight for the variable sweep, and a large part of the mission is flown subsonically. For this reason, the variable sweep machine offers additional performance versatility at the expense of overall attack productivity at a constant radius of action.

Still another opportunity for development in attack systems by 1975 lies in flexible operation from forward bases. Aerodynamic and propulsion system developments may offer some small improvements in take-off distances, perhaps of the order of 10 percent. Small improvements will also be available in unprepared field operation. However, the point of diminishing returns is being reached in these areas, and the big breakthrough to VTOL will probably be made by 1975, at least for subsonic machines (Fig. 9).

For VTOL, the weight trade-off will be between propulsion system weight and fuel weight since the introduction of VTOL will imply shorter required radii of operation. Whether all of the radius that must be sacrificed to attain VTOL can sensibly be assumed to be radius-over-friendly-territory is a question that must be determined by the military. At any rate, if we eliminate some of the fuel in a typical attack aircraft and replace it by enough propulsion to make the vehicle VTOL, we shall reduce the radius from 600 to 200 miles. But, as already stated, whether the resulting machine is the proper compromise is a question that the contractor alone cannot answer.

Let us turn, then, from considerations of possible airframe improvements in the 1965–1975 time period to those expected in the electronics complement. It is certainly incontestable that, for attack systems, the most rapid advances are now being brought about in electronics rather than in airframes. Let us again refer to the 1965 system for comparison (Fig. 10). It contains approximately 3,000 lbs of electronic equipment, occupying about 100 cu ft. We believe that, by 1975, this 3,000-lb weight could be reduced to 1,800 lbs and the volume required for installation may drop from 100 to 60 cu ft. In the A2F development, early as it is, we already see the indications of increased reliability available from these more modern electronic designs, and we are confident that this trend will continue unabated through the 1975 time period. We are convinced that those who are the greatest skeptics about the use of extensive electronic systems will be ready to accept considerably more 10 years from now.

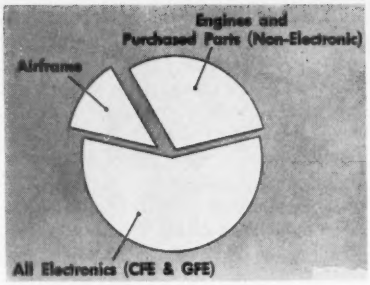



Fig. 4. A2F-1 cost division.

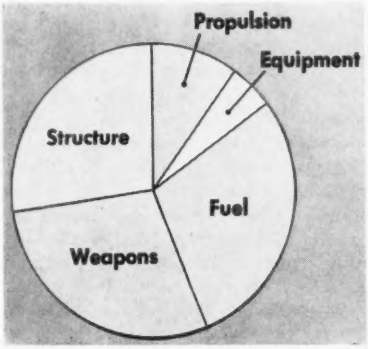



Fig. 5. Gross weight division, 1965.

If then, by 1975, we reduce the weight and volume of electronic equipment, what will replace it? The space and weight saved can best be used to add additional attack capability in three areas—target acquisition, weapon accuracy, and survivability—and the biggest unknown is whether this added capability becomes part of the aircraft complement or part of the weapon complement.

To explore this further—our operational analysis and economic studies clearly indicate that, under normal battlefield conditions when the aircraft can be expected to last through a reasonable number of missions without loss to enemy defenses, it is cheaper to put the intelligence in the aircraft, where it can be reused, rather than in the missile which is expended (Fig. 11). There are, of course, practical technological limitations; these we shall identify for the 1975 time period.

In the field of target acquisition (Fig. 12), we believe that considerable strides will be made in both active and passive detectors. Radar itself is still nowhere near its limit, and substantial improvements may be looked for in resolution, range, and clutter suppression. By using somewhat higher frequencies, new devices such as parametric amplifiers, and digital techniques, we expect by 1975 to attain 50 percent greater resolution, 30 percent better range, and 70 percent more anti-jam capability.

In addition to radar, we expect the operational applications of many other devices such as infrared, vidicon displays to amplify clear-night vision, and optical frequency scanners using the new maser and laser techniques. Magnetometer devices for use in target acquisition and passive sensing of target emissions are certainly in the picture. Today's aircraft, by providing all-weather acquisition of any moving target, represent a tremendous stride forward and will find their major usefulness in disrupting the enemy's ability to resupply his battle area. The next stride forward, then, is the ability to find all of the hidden stationary targets

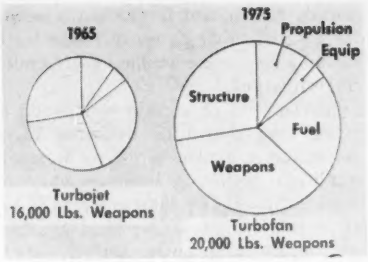



Fig. 6. Turbofans for payload.

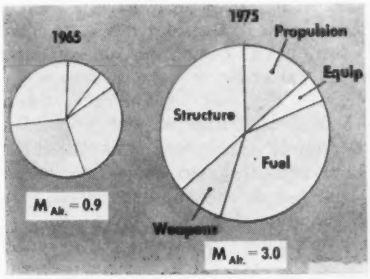



Fig. 7. Supersonic cruise at altitude.

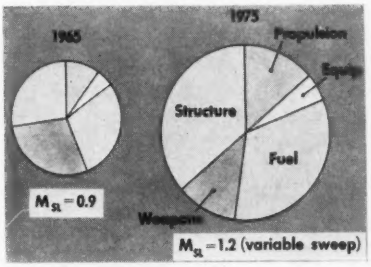



Fig. 8. Supersonic dash at sea level.

already in position in the battle area, targets that either are warmer than their surroundings, are metallic, or are emitting radiation.

In the field of accuracy—in 1965 a given weapon can be delivered to a given target under zero-zero weather conditions within an accuracy which is several times better than expected to be attainable visually under ideal weather with no enemy defensive activity. But why can we not do even better than this? Where do the errors originate? Our analyses show the following accumulation of errors: The maximum error is due to steering; moderate equal contributions come from the computer itself, the radar, and the dispersion due to the vagaries of the atmosphere through which the weapons drop. The minimum errors come from the input data from the inertial system, the air data system, and the differences in individual bombs.

A realistic estimate of the technical improvement in aircraft system accuracy by 1975 shows only a 20 percent gain over the system begun in 1965. This suggests again that the point of diminishing returns is being reached, but we would certainly hesitate to say that such accuracy, though quite remarkable by present standards, is all that will ever be needed. At a modest weapon release point a mile from the target, this still represents an error which is certainly substantially larger than the lethal radius of a practical-sized conventional warhead against a small hard target such as a tank or a pillbox. The ultimate problem, of course, is to match error and lethal radius or target size. For small hard targets, such as tanks, it may not be practical, within this time period, to achieve the desired accuracy by retaining all the intelligence in the aircraft. Ideally, we should like an accuracy which is also independent of launch range. The problem, then, is to put an intelligent terminal homing capability in the missile without raising its cost to a prohibitive level. This can be done within the stated time only by using a television or vidicon unit in the weapon. Naturally, the usefulness of this weapon will be weather-limited, but in its operating environment it could provide an accuracy of 5 ft.

To look at the bright side—making this an all-weather weapon will give us something to do in the next time period. We believe that, well before 1975, it will definitely be possible to develop a limited-weather missile having a level of accuracy not attainable in the aircraft itself. Grumman's development work to date, and what we know of research efforts by others, indicates the feasibility as well as the usefulness of such a weapon. It will provide an important new attack capability in the limited-war theater.

Finally, we should discuss briefly anticipated developments in the area of survivability. The 1965 attack aircraft has been developed to fly for long periods of time under adverse weather conditions at very low altitudes, with terrain clearance displaying for the pilot complete topographic information in the quadrant ahead. Improvements in the display of this information are anticipated. With this terrain-clearance capability (Fig. 13), attack aircraft will survive by penetrating enemy territory in the enemy's radar shadows. Additional survivability is provided by passive ECM equipment, armor, air-to-air weapons, and the multiengine installation. Against IR homing missiles such as Redeye, the best defense of attack aircraft is to penetrate under adverse weather conditions.

Although this much emphasis gives the aircraft a better-than-even chance against anticipated enemy defenses by 1965, greater emphasis will have to be placed on survivability in future attack systems. A higher degree of active ECM capability is strongly suggested for the future time period, as well as specific weapons for use against enemy defensive radars either on the ground or in the air. The Navy's new anti-radiation missile will be a valuable addition to our attack capability.

Until recently, it has been felt intuitively that the enemy could not afford to defend each small potential target on the battlefield in a limited war. Although the Hawk and Mauler-type systems present a threat to the accomplishment of the close support mission, they are not an economical defense for every bridge, tank, and pillbox so they are not the major threat. However, possible improvements in airborne interception techniques and systems, especially against low-altitude penetrations, will require an increase in the continual emphasis on the maintenance of local air superiority over the battle area. Further development of longer-range air-to-surface weapons with terminal guidance will permit greater flexibility of action of the attack aircraft.

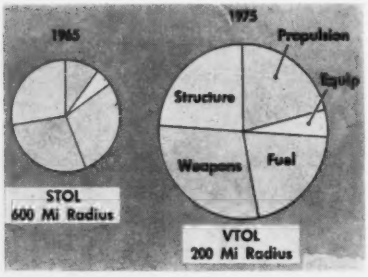



Fig. 9. Forward area operation.

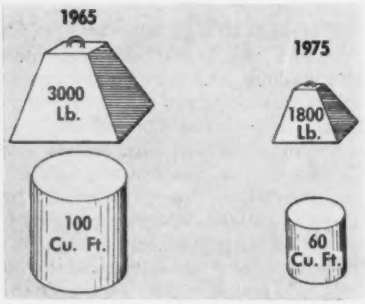



Fig. 10. Electronics weight and size.

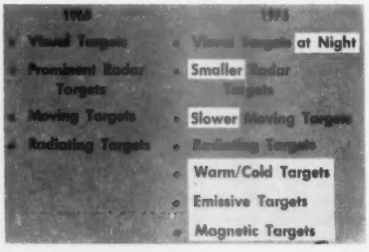



Fig. 12. Attack targets acquired.

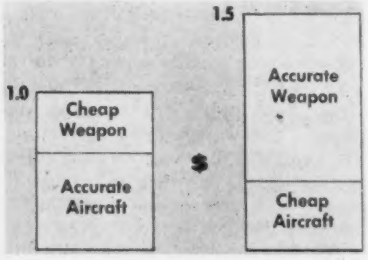



Fig. 11. Cost to kill a target, 1965.

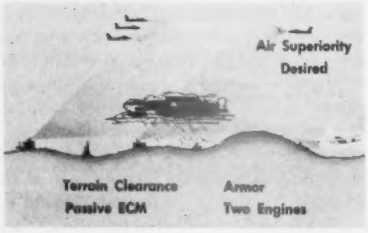



Fig. 13. Survivability, 1965.

+ + +

The Editors welcome letters from readers, although none can be acknowledged. All must be signed, but identities will be withheld on request.

# He's solving a real estate problem

This AMF engineer's job is determining how best to move big missiles off shore for launching. Should they be floated out horizontally, flooded to an upright position, and then launched? Or, would it be more feasible to barge them out? Might they be moved to or assembled on "Texas Towers," or would a causeway or simply land-fill be the answer?

Behind the project is our shrinking real estate at launching sites, plus the hazards inherent in launching Saturn-sized missiles (and the coming, nuclear-powered missiles) near other installations. Off-shore launching may be the answer.

Feasibility studies of all types are an AMF specialty. What kind of remotely controlled machinery is required to service nuclear-powered aircraft? What kind of habitation could be built on (or under) the surface of the moon? What sort of machines (manned and unmanned) could survey the moon's surface without, for example, falling into a fissure? What is the best way to assemble a space station? All these are problems AMF engineers are presently investigating.

If your problem is the first of its kind, AMF will not, of course, have met it before. But AMF's long experience in accepting totally unique challenges gives it an advantage enjoyed by few other organizations concerned with ground support, launchability and space environment. To get further information write American Machine & Foundry Company, 261 Madison Avenue, New York 16, N. Y.

AMF

ngineering and manufacturing AMF has ingenuity you can use...

**AMERICAN MACHINE & FOUNDRY COMPANY**

## Fleet Carrier Problem (Continued from page 13)

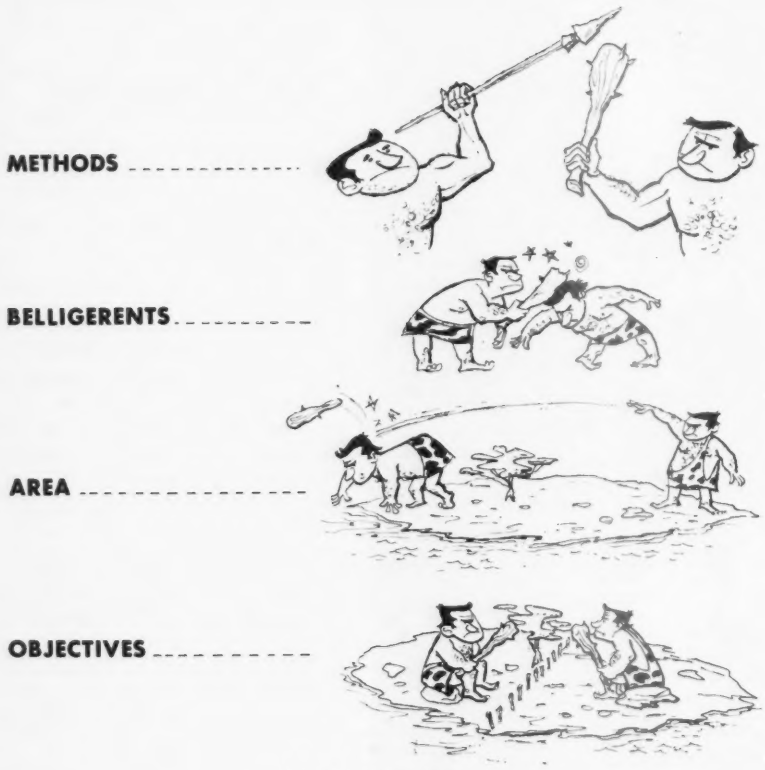



Fig. 1. Limiting factors.

The improvements in ordnance and light-attack aircraft reliability, along with a limited inventory of high-performance VA aircraft, will, in effect, double the Fleet Carrier attack potential (Fig. 4). However, to realize the benefits of this increased attack potential, the problem of providing "good" targets for the light-attack aircraft must be solved.

### Reconnaissance Problem

In order more closely to approach full utilization of Fleet attack potential, a third limited war problem area—reconnaissance—must be given emphasis. This is an element equal in importance to increased aircraft availability and improved ordnance.

For example, in Korea, pilots frequently dumped ordnance in the ocean or on unimportant targets because the reconnaissance systems were incapable of providing targets at the rate they could be destroyed by the attack systems.

In the Korean conflict, pilot reports of new targets occurred once in about 16 sorties. If this rate is added to the photo interpreter's discovery rate of new targets and the rate at which electronic intelligence aircraft acquire new targets, then a target reconnoiter rate as a function of mission radius can be determined. With these calculations, it can be noted that the present-day Fleet Carrier also has a reconnaissance "void," or a lack of reconnoitered targets for the attack aircraft. The conclusion is evident: The present-day total reconnaissance system is incapable of acquiring new targets at the rate attack aircraft can kill targets. Increased light-attack aircraft availability must be supplemented with improved reconnaissance if overall attack effectiveness is to be improved (Fig. 5).

These requirements cannot be included in the "simple" light-attack aircraft concept, but the light-attack design must be such that maximum utilization of this information is achieved.

### Light-Attack Aircraft

The light-attack aircraft is required for close air support of the ground forces and interdiction of the battlefield (Fig. 6). Because of the bomb tonnage required to kill the thousands of limited war targets, the aircraft must fly many sorties from carrier decks and from the rear of the battle area. Simplicity and low cost are essential to providing the aircraft numbers and the low maintenance times to ensure high sortie rates. This aircraft would perform highly accurate visual attacks both day and night, and be capable of

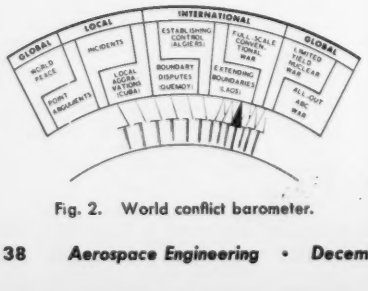



Fig. 2. World conflict barometer.

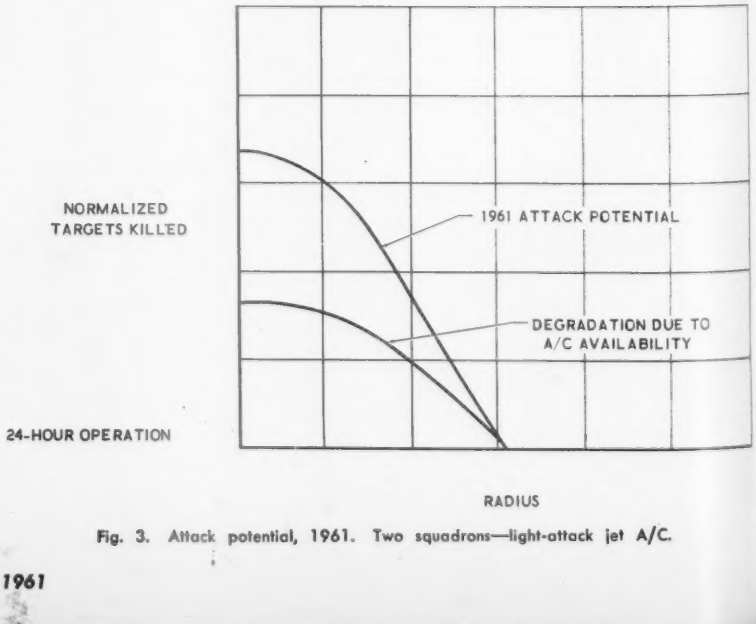



Fig. 3. Attack potential, 1961. Two squadrons—light-attack jet A/C.

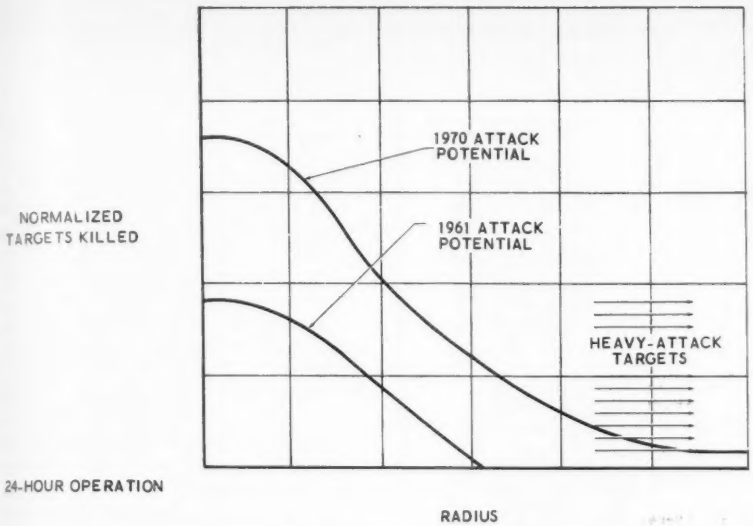



Fig. 4. Attack potential, 1970. Two squadrons—light-attack jet A/C.

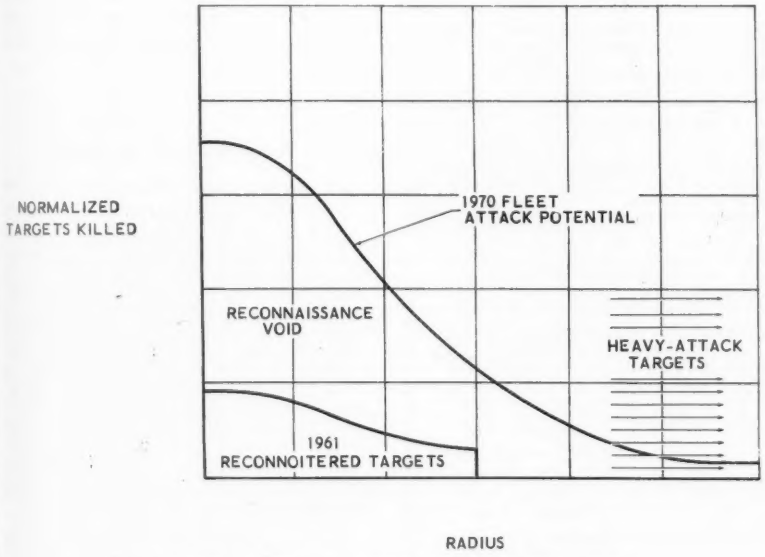



Fig. 5. Attack effectiveness. Two squadrons—light-attack jet A/C.

navigating through weather to and from the target objective area.

It is obvious that the common denominator of the solutions to many of these problems is the use of electronic equipment. The requirements for this aircraft are being established at present by the Chief of Naval Operations. The first step in achieving simplicity must be the elimination of functions not contributing to the basic mission. After this is accomplished, a carefully worked-out system to provide for the basic functions must be designed. This system should allow for flexibility by supplementation for specific missions. It must also allow for future changes in supplementary equipment and adaptation to varying conditions in many parts of the world of both environmental and cooperative forces.

This presents the major challenge to the aircraft and electronics industry. Fortunately, recently developed equipment based on transistorized, printed circuit, plug-in module design has shown large improvements in reliability. Automatic check-out techniques permit accurate testing of equipment without removal from the aircraft. These designs allow high-density packaging with minimum heat rejection and cooling problems—a major aid to the aircraft designer.

However, it will be necessary to hold costs within reasonable limits and reductions must be accomplished through establishment of minimum systems requirements for this aircraft. All elements of the system should be designed to compatible accuracies established by proper systems engineering. After this is accomplished, allowance must be made for a thorough test and development of the system in its environment. Despite the best intentions of designers and engineers, problems in equipment affecting reliability can usually be found in small detail design areas which are "smoked-out" only through operation of the equipment.

## Summary

The Fleet Carrier Attack Problem in a future limited war was previously stated in terms of the accurate delivery of large quantities of HE on profitable targets. The light-attack aircraft concept provides a low-cost, readily maintained reliable vehicle which solves the primary problem of aircraft availability. Such aircraft will have navigation systems and electronic countermeasures equipment sufficient to assure all-weather day or night delivery of weapons against visual targets defended by guns, missiles, or interceptors.

The problem of acquiring appropriate targets will be solved by a high-performance reconnaissance aircraft capable of penetrating the most distant missile defenses. The use of the Fleet Carrier's complements of all-weather attack aircraft or sophisticated systems against difficult defensive targets will reduce the systems requirements for the light-attack aircraft.

In order to equip the Fleet Carrier with the balanced strike aircraft complement recommended, positive action is required in certain development areas (Fig. 7). The general performance and operational capabilities required for both types of aircraft are well within the current state-of-the-art. The aircraft will, however, benefit appreciably from advances being made in high-lift devices and low-speed handling capabilities, and from increased systems reliability projected for this time period.

- LOW WEIGHT
- LOW COST
- ALL-WEATHER NAVIGATION
- DELIVERY ACCURACY
- HIGH BOMB TONNAGE
- CARRIER AND MARINE SUITABLE
- EASILY MAINTAINED

Fig. 6. Light-attack aircraft.

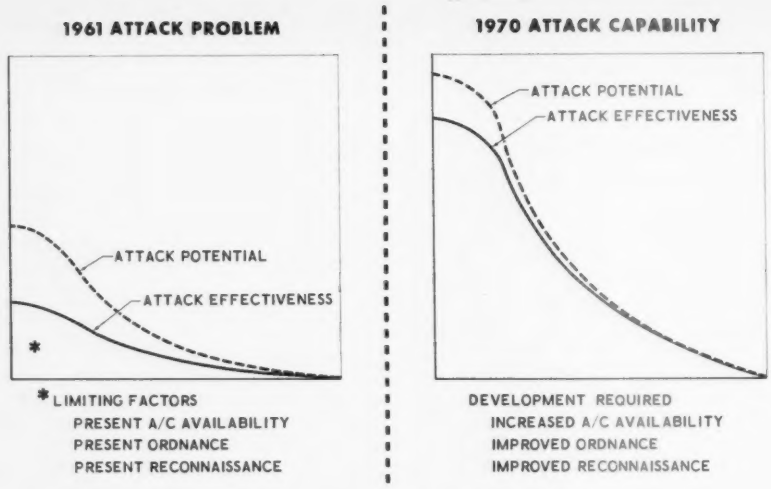



Fig. 7. Increased attack effectiveness.

Perhaps it is timely to point out that no satisfactory small engine is programmed at present for the light-attack aircraft to provide the desirable feature of twin-engine reliability.

The systems reliability required for highly accurate navigation, target acquisition and weapon delivery will require an accelerated development schedule with major emphasis placed on simplification of electronic components, through the use of solid-state and other new devices.

The predicted fluidity of limited war environments and the increasing tendency toward small, autonomous and diversified combat units require development of an efficient intelligence gathering and information generation system and communication and control systems to provide the proper environment for the light-attack aircraft.

In conclusion, therefore, the major Fleet Carrier effectiveness dividends in limited war will result from the development of a balanced attack team. The light-attack unit of this team can be "simple" only if it is designed to operate with full cooperation of the other team units, and not "over-designed" in an attempt to fulfill the entire attack role with a single aircraft.

✦ ✦ ✦

## Antisubmarine Warfare Problems (Continued from page 15)

the forward area. Barrier operations will be conducted to block submarine sorties into the open ocean. Protection against missile-firing submarines will be provided in the waters contiguous to the Atlantic and Gulf coasts. The protection of shipping will be realized as a result of all of our ASW operations, as well as close and distant escort convoys. So much for the size of the task. Now, how well can we accomplish it?

### Performance

Our current operational readiness in ASW is dependent upon several factors, all of which are intimately related. Such factors are, broadly, quantity and quality of weapons and equipment and performance. Of these, performance is the one that we, the operators, can influence the most. As to the others, we must make recommendations and depend upon our powers of persuasion, and day this is one of our better opportunities.

Since performance is one aspect of ASW which deserves a cheerful word, let us consider it first. There has been a gradual but steady and significant improvement in the ASW effectiveness of our individual ships and aircraft, as well as in their ability to coordinate their ASW effectiveness with other units. Even so, we are barely holding our own with the conventional submarine.

ASW demands teamwork, and we are continuing to refine our ASW tactics in the course of numerous minor exercises, regularly scheduled large-scale task force hunter-killer escort of convoy barrier, and continental defense exercises. An organized investigation of the problem of countering the threat presented by the nuclear submarine is well under way. We have an advantage over the Soviet in this regard. Our own nuclear submarine program provided this kind of opposition a few years in advance of the appearance of the Soviet nuclear submarine. Certainly the nuclear submarine represents opposition of appalling proportions.

### New Weapons and Equipment

Whatever improved performance we possess can be attributed in part to the gradual introduction of new weapons and equipment. Detection ranges above the thermal layer are constantly expanding, and there will be improvements below the layer with variable depth sonar, deeper dipping helicopter sonars, and conversion zone and bottom bounce equipment when we get them. We can expect better search performance with patrol plane sonobuoys on completion of installation of the Julie/Jezebel system. The lessons learned and the tactics developed from the experience of the specialized ASW task groups such as Alfa, Bravo, and Charlie have contributed markedly to our improving performance. These task groups were formed and given a mission to specialize in ASW to the exclusion of all else.

Task group Alfa was formed a little over 3 years ago with seven destroyers, two submarines, one carrier with its ASW air group, and a shore-based patrol squadron. The purpose of the group is to develop and evaluate tactics, equipment, and weapons under operational as opposed to controlled conditions. There is no intention of supplementing or duplicating work being done by the operational development force. To do this, and have results that carry any validity, it is obviously necessary that the group always be at a high state of training; the first half of all sea periods are thus devoted to rigorous basic ASW training. This, coupled with the fact that the same ships have remained as

elements of Alfa, has made it possible for Alfa to become what is probably the most effective ASW hunter-killer group in the world, and to make significant contributions to tactical and material development.

Bravo, formed about a year later is similar to Alfa except for the permanent assignment of submarines. Bravo has also made notable contributions, and there now is a healthy and productive rivalry between the two groups.

Charlie is a group composed of destroyers and shore-based air. As a result of the operations of these groups, we have learned what we can do with our present equipment and what our shortcomings are.

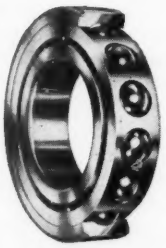
Two other related factors which affect our ASW readiness are the quantity and the quality of ASW equipment and weapons. One category of weapons, the torpedo, is common to all ASW agents. In fact, one torpedo or another is the primary conventional weapon of all. The Mark 44, dropped by aircraft or destroyers or both near the target, circles until it makes sonar contact and then attacks. Performance is good when the drop is accurate. The Mark 37 is a long-range acoustic torpedo which can be used by both destroyers and submarines. It is an excellent weapon. We do, however, have reliability problems with both of these torpedoes.

With torpedoes there is also the problem of preparing against constantly progressing antagonists. To combat the nuclear submarine will mean that our ASW development and procurement programs remain in high gear. We shall need better torpedoes and reliable long-range delivery to keep up with our end of undersea warfare. The development of an operationally significant potential to employ the longer-range weapons is hampered by the slow delivery of modern weapons to the fleet.

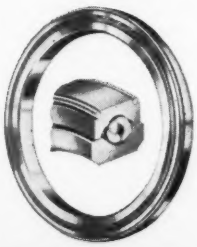
### Electronics

At present, in our surface ship weapons systems, we have 19 ships equipped with Asroc. Two years hence there will be nearly a hundred as a result of modernization and new construction. This is a modern weapons system of major importance, despite some trouble in reliability and maintenance of the fire control system. Unfortunately, this is true of many new electronic systems. Heat dissipation in electronic assemblies is the big problem. The high incident temperature in electronic devices demands new means of cooling by other than conventional means of large blower or fan systems. The solution we want is the elimination of the heat producer—a few thousand vacuum tubes, for instance. Solid-state physics seems to be our hope here.

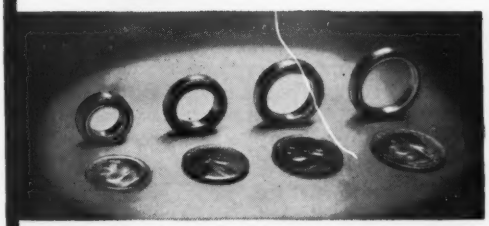

a new design concept...



**HDR SERIES** High precision radial ball bearings with maximum ball complements in deep groove races uninterrupted by filling slots or counterbore — extra high capacity — made in four metric series, in ABEC 3 and ABEC 5 precision grades.



**T SERIES** Thin-section, high precision radial ball bearings. Type TCR with maximum ball complement and retainer — Type TCF with full race ball complement — Type TWF with unique integral shield.



**MIDGET T's** Small, thin-section radial ball bearings with maximum ball complements and one-piece retainers — high concentration of load capacity in minimal space results in tremendous space savings.

**FUNCTIONAL ADVANTAGES EXCLUSIVE WITH PATENTED SBB BALL BEARING CONSTRUCTION**

Split Ballbearings have many advantages over conventional ballbearings because of our exclusive and patented method of construction. The result is a new kind of precision ballbearing with the following superior performance abilities:

**MORE LOAD CAPACITY** — up to 56% more radial capacity than conventional Conrad-type bearings while maintaining full thrust capacity in either direction. **LONGER SERVICE LIFE** — up to 280% more life than conventional Conrad-type bearings, without sacrificing load capacity. **ONE-PIECE RETAINER** — strong, light, precision made. **SPACE SAVING** — more capacity in a given bearing envelope means smaller bearings may be used. **LOW TORQUE** — maximum ball complements and precision one-piece retainers provide better load distribution within the bearing, effectively reduce starting torque, and minimize running torque. **GREATER RIGIDITY, LESS DEFLECTION, INCREASED RESISTANCE TO SHOCK LOADS** — all these advantages derive from using maximum ball complements in deep groove bearings without filling notches or counterbored rings . . . possible only with Split's patented construction method. **INTEGRAL SHIELDS** — truly integral shields in thin-section bearings . . . no ring distortion. **SPECIAL DESIGNS** — Split Ballbearing's method of construction brings new solutions to difficult bearing problems. As a result, many of these incorporate special bearing designs. You are invited to consult with our Special Bearing Engineering Group for new approaches to your particularly difficult bearing problems.

split ballbearing

SBB DIVISION OF MPB INCORPORATED

LEBANON, NEW HAMPSHIRE

## Sonar Detection

Another long-range delivery agent anxiously awaited in the fleet is Dash, capable of attack by remote control from a destroyer at our constantly increasing sonar detection ranges. About 25 hangars and landing platforms are already installed in our destroyers. Our long-range sonar detection performance is improving. By mid-1963 we shall have well over a hundred ships equipped with a high-powered, long-range SQ8-23 sonar. These lower-frequency sonars are reaching way out into the surface layer. This is why it is so urgent that we catch up on our weapons. In spite of a current capability for long-range detection, our destroyers must nevertheless still close in on their targets to vulnerable point-blank range in order to attack.

Let us now examine the airborne weapon system.

Jezebel, our portable sound surveillance system, and Julie, our localization sonobuoy system, have been installed in nearly all of our patrol aircraft; our new S2F-3 trackers, carrier-based, have both Julie and Jezebel.

Two R&D projects merit special mention. First, the development of an airborne, as well as surface, search radar that will reliably detect and expose snorkel or masts in an average sea is urgent. Nuclear submarines must occasionally expose masts of one kind or another. Second, devices utilizing infrared to detect the wake of the submerged submarine look promising and should be pushed.

The helicopter is a versatile and continually improving member of the hunter-killer team. Around the clock, day and night, operations have become routine with the HSS-1F. We shall soon begin to receive the new turbine-powered HSS-2.

Submarine sonars are constantly reaching out to longer ranges with their passive listening array.

Radio, radar, and sonar countermeasures are of great importance. Improvement in electronic countermeasures will have progressed significantly by 1963.

The program of submarine quieting is beginning to bear fruit. There is also an energetic program for providing the conventional submarine with a quiet snorkel capability.

## Communications

Communications is the voice of command. Our exercises repeatedly emphasize the importance of secure, reliable, and rapid communications among the various ASW commands, as well as among the various units at sea and in the air. There has long been a need for reliable communications between submarine and other ASW forces. Furthermore, positive identification by aircraft of friendly submarines is mandatory to promote mutual support and prevent accidental attack. This is a most urgent requirement, long overdue for solution. There also exists a need for secure long-range underwater communications among our own submarines.

With regard to the employment of airplanes in ASW, they are indispensable in those situations which call for precise delivery and positive control in the exercise of human judgment, especially in limited war. We visualize a continuing need for aircraft which will perform essentially the same functions as those now in the fleet, with improvements to the limit of present technology. Small percentage improvement is not sought, and, if offered, is not bought because it costs too much to get marginal improvements. The new aircraft coming off the production lines reflect this philosophy of development.

We have touched on the performance, quantity, and quality of our hardware and the adequacy of our procurement program. In this connection, one disturbing philosophy is that by which work on a certain piece of equipment is erased from the books because its further development has reached a roadblock. Sonar is sonar and that is that. If we want to do the job better, a new and spectacular development will have to be made somewhere else. This is far from the truth. There is not one piece of existing antisubmarine equipment that cannot be vastly improved today by techniques within the state of the art.

Qualitative improvement in our existing equipment is urgently needed now. We cannot afford to wait for the big breakthrough. The distressing thing, however, is that, principally because of budget problems, it takes us years to get working hardware to the fleet.

## The State of Readiness

At this point it may be well to appraise the state of our readiness in ASW, as related to the various areas of ASW responsibility.

First, the forward strategy. Between Polaris and the fleet we have a strong capability to strike at the source in case of a general war. However, increased capability for mobility and dispersion through the use of submarine tenders and bases beyond home waters tend to emphasize the continuing need for manned aircraft in weapon delivery —both seaplane and landplane. It is difficult to assess the probable success of blockade efforts, and it would be dangerous to make ASW plans based on a high effectiveness. In general war, our submarine attrition patrols operating off enemy bases in concert with our allies would give a good account of themselves during the first few weeks, and thereafter depending on the survival and adequacy of their logistics. We can also expect initial effectiveness in our barrier effort—a surveillance system in times of tension or in some degree of limited war—and in an attrition effort in large-scale limited or general war. As long as sufficient air and surface forces are available to keep penetrating submarines submerged and therefore susceptible to sound detection, we have a fair early warning capability.

In general war, we would reserve the remainder of our scarce ASW forces for defense of the striking fleet, its logistic support, and the very highest-priority military convoy. Any future limited war would doubtless involve submarines and ASW. Limited numbers of troops would move by air, but the bulk would go by sea, as well as more than 99 percent of all equipment, supplies, and resupplies. We do not control the amount of submarine opposition to be encountered—it might be large or small, but it would certainly be present. Our forces are too thin for us to stay in effective combat for more than a short time. Then we would be faced with a choice—escalating to bigger weapons and bigger targets or surrender of important sea lanes and real estate and sacrifice of our friends and allies while we frantically catch up in ASW forces and logistics.

## Conclusion

Improvement of our present ASW posture cannot much longer be deferred if our Navy can expect to meet its paramount responsibilities in the defense of the interests of our nation. As a practical matter, we would be wise to put emphasis on those things which would pay the quickest returns.

A large part of our problem in building up our ASW capabilities is a general belief that ASW is not one of those defense elements requiring a quick reaction time. It is felt, and rightly so, that first of all, we must have a nuclear capability in hand and ready to use instantly. As a result, it receives major attention because it is also felt, and this time wrongly, that ASW is an element that can be built up after a war starts if we have a sound nucleus. With the opposition we face, and the total urgency of maintaining seagoing communications with our allies, we cannot possibly build up fast enough to avert serious trouble. We need adequate stocks of systems and weapons, and must be ready in training and tactics to use to maximum advantage the best designed and most reliable equipment available today and in the future.

times that amount. I certainly do not mean to imply that a single 5-in anti-aircraft shell is comparable with a long-range surface-to-air missile in effectiveness, but the above example does illustrate the increase in cost being experienced in air defense systems.

### The Threat to the Fleet—Time Versus Type

The airborne and space vehicles which will constitute the threat to the Fleet during the next 50 years seem to group themselves into three primary categories, summarized in Fig. 1. These are aircraft, missiles, and space systems. Within the aircraft category, the threat is reasonably well-known and the performance characteristics can be well-established. Aircraft will make up the primary threat through the late 1960's. Missiles will establish themselves as a threat from the mid-1960's on, and will continue through the 1970's, becoming the primary threat in the late 1960's and early 1970's. Initially, the threat presented by missile systems will consist of high subsonic or low supersonic air-to-surface and surface-to-surface capabilities. During the late 1960's, missile performance will extend well into the supersonic regime with ranges of 300 miles or more and will include both high-altitude and low-altitude profiles. During this time period, there will also be a threat from the submarine-launched ballistic missile as well as from aerodynamic missiles of the boost-all-the-way, boost-sustained, and boost-glide types. This time period can also see the use of a supersonic low-altitude penetrator similar to a system now being studied at Chance Vought. During the late 1960's, shore-based ballistic systems and nuclear-powered systems can provide a threat to the Fleet provided adequate information relative to the position and course of the Fleet is known. Satellite surveillance in the gross sense can become operational in the 1960's, with high-resolution systems in the 1970's.

### Lunar Base

In the last quarter of the 20th Century, it may well be possible to utilize the moon and later, perhaps, Mars as bases for military operations (Fig. 2). Although the strike forces based outside this planet would, in all probability, be prime-retaliatory or second-strike threats, the weapons available to such a force could be directed against Fleet units. The use of such forces against the Fleet would depend on the quality of the threat posed by the Fleet and the means available to the enemy to counter such a threat. Fleet defense components which are designed for effective defense against low-orbit satellites will very likely stand it in good stead even against battle forces capable of ranging throughout the inner planets of our solar system.

Looking forward to the next century, one might ask the questions, "What will be the nature of Fleet missions, and thus of the force to perform those missions, at the onset of the 21st Century?" Suffice it to say here that missions will continue to exist on this planet both in limited war as well as general war and the Fleet forces required to perform these missions must be defended.

### The Threat to the Fleet—Type and Performance

Fig. 3 summarizes the preceding information in terms of speed and altitude performance for the three categories of enemy threat. The horizontal lines represent increases in order of magnitude (factors of ten) of the speed and altitude capability of the threat. With regard to speed, we note that missiles cover a considerably wider band than do the other threats. The same is true of the altitude spectrum. From this it might be inferred that Fleet defense against the missile threat will prove to be relatively more difficult than defense against the other two categories. In other words, the wider performance spectrum characteristics of the missile threat will introduce a wider variety of technical problems in the development of effective defenses against this threat.

We have seen previously that missiles in an advanced time period will depend to an increasing extent on satellite surveillance data. Thus, it may be more reasonable in these advanced time periods to direct a significant portion of our defense efforts against the space systems providing surveillance data, and, in this way, reduce or eliminate the effectiveness of advanced missile attack systems.

Existing systems, along with those under development, appear to be adequate to deal with the projected threat until the latter part of the present decade. Free-fall weapons accompanied by limited use of relatively short-range stand-off weapons will constitute the primary threat to the Fleet through most of the 1960's. The F4H with Sparrow III missiles, and the F8U with advanced versions of the Sidewinder missile, supported by contemporary surface-to-air missile systems, appear

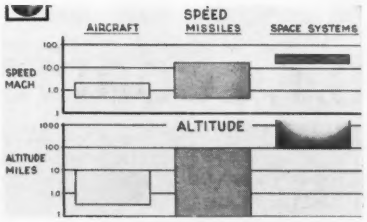



Fig. 3. The threat to the Fleet—type and performance.

adequate to handle such a threat. However, in the late 1960's, requirements for new operational defensive missile systems will begin to present themselves as the primary threat to the Fleet shifts from manned aircraft to missiles.

Toward the last quarter of this century, space systems are expected to be significant elements of the threat to the Fleet. As previously indicated, their first use will be as surveillance systems used in conjunction with both ballistic missiles and supersonic low-altitude penetrators. At some later time period, the introduction of deorbit weapons or space-based systems will require the development of a defensive capability.

### Vertical Probe Defense System

Development of space-based systems will require extending today's anti-air missile systems beyond the limits of our atmosphere. A mobile antisatellite system (Fig. 4) will probably be required.

This antisatellite system can be an orbital system which is essentially an energy-matching system analogous to today's anti-air aircraft. Or, it can be a nonorbital vertical probe system—in effect, an "antisatellite gun." The nonorbital probe system does not match the total orbital energy of the target satellite; therefore, it is a smaller, mobile, and less expensive system capable of performing a covert satellite-neutralization or reconnaissance mission. Any antisatellite system should be capable of

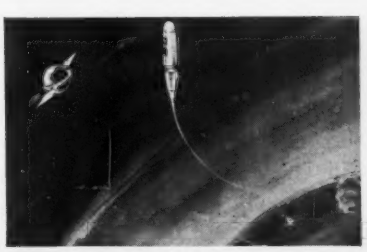


Fig. 4. Vertical-probe defense system.

# FUEL HANDLING

## B.F.GOODRICH PRODUCES THE ANSWERS

**SURGE BOOTS**—absorb hydraulic shock.



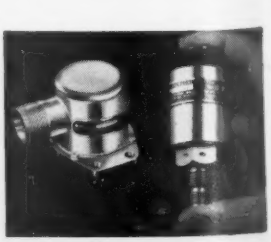
**FLEXIBLE CONNECTORS**—for internal fuel lines.

The aerial refueling system on the U. S. Air Force KC-135 jet tanker delivers fuel at an extremely high flow-rate—yet must disconnect instantly when required.

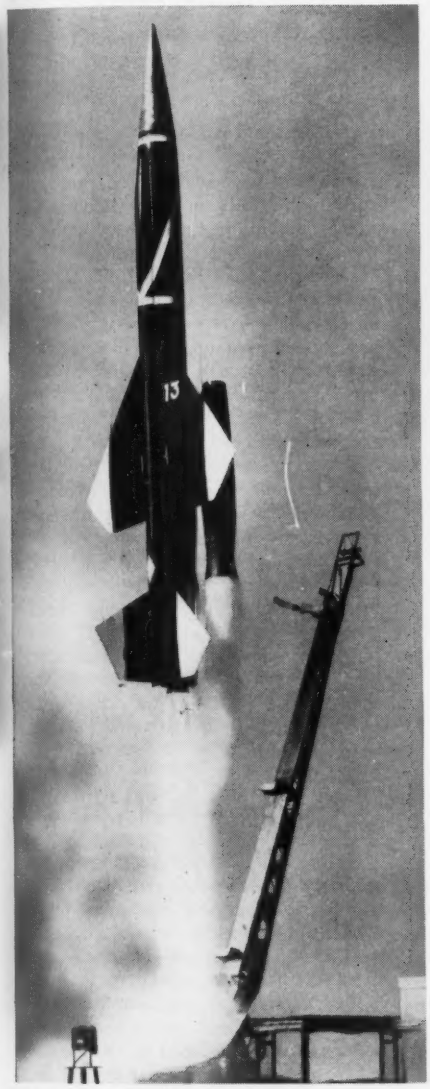
To take the tremendous shock pressure when flow is interrupted, B.F.Goodrich designed and built for Boeing a double-walled surge boot to carry fuel in the flying boom extension. A pressurized air cushion between the walls of the boot dampens shock loads, permits fast refueling with safety.

B.F.Goodrich designs and produces special products for a wide range of fueling requirements—surge boots, flexible fuel line connectors, fuel cells, hose, vapor barriers, and others for aircraft...motor cases, insulator liners, and solid propellants for rockets and missiles. For help in *your* applications check *B.F.Goodrich Aviation Products, a division of The B.F.Goodrich Company, Dept., AS-12, Akron, Ohio.*

**PRESSURE SWITCHES**—BFG switches actuated by precision, Omega-design bellows perform many critical functions on jet engines such as indicating adequate fuel pressure, actuating afterburner igniters and unlocking nozzle area controls.



# FOR UNUSUAL REQUIREMENTS



**EXPULSION DIAPHRAGM**—BFG supplies a special flexible diaphragm mounted in the fuel cavity of the Bomarc supersonic area defense missile. Diaphragm expels hydrocarbon fuels under pressure to external ram-jet engines.

**WEIGHT-SAVING FLEXIBLE FUEL CELLS**—This T-38 twin-jet trainer, made by Northrop, is one of many current aircraft using BFG fuel cells. Constructed with special fuel-resistant compounds, these cells are strong and lightweight. BFG fuel cell manufacturing is backed by complete development and test facilities.

**SOLID-FUELED ROCKET MOTOR CASES**—BFG offers complete capability in filament-wound rocket motor cases—also insulators. These glass fiber reinforced plastic structures are lightweight, strong, and are produced in many sizes and configurations.

**B.F.Goodrich aviation products**

- GUIDANCE FOR LONG RANGE AAM
- GUIDANCE TRANSFER FROM SHIP TO AIR
- LONG RANGE TARGET DISCRIMINATION AGAINST SEA CLUTTER
- COUNTER-COUNTERMEASURES DEVELOPMENT
- LOCALIZATION OF IR SOURCES AT LONG RANGE
- MISSILE TRAJECTORY & IMPACT POINT PREDICTION
- SECURE COMMUNICATIONS - SATELLITE TO SHIP
- HIGH CAPACITY DATA PROCESSING & INTEGRATION
- POWER, SHIELDING CRITERIA FOR RADIATIVE WEAPONS
- WARHEAD NEUTRALIZATION WITHOUT DETECTION

**Fig. 5. Fleet defense missile systems—technical problem areas.**

being air-, ship-, or ground-launched. Current analyses, however, indicate that significant cost effectiveness advantages accrue to a ship-launched system.

At this point, something should be said regarding the projected operational life of current defense systems as well as defense system concepts under study. When an effective defense system has been put into operation, it will continue to perform a useful function as long as the threat against which it was designed continues to exist. The enemy will continue to employ a given threat as long as he feels it is profitable for him to do so. When defenses have been developed which make it unattractive for him to apply a given threat against the Fleet, he will attempt to put into operation other threats against which we have no effective defense.

## Fleet Defense Missile Systems—Technical Problem Areas

Fig. 5 summarizes some ten technical problem areas typical of those which will be encountered during the next 50 years of Fleet defense missile development. Initially, these problem areas will be concerned primarily with guidance and control of the defensive missile itself. Such problems of guidance are related particularly to the development of long-range air-to-air missile systems. As time progresses, however, the technical problem areas will tend to shift to the detection of, and gathering of information on, the threat. For example, it is necessary to detect and locate the position of a submarine-launched missile in order to employ a defense against it. Concurrent with the detection problem goes the problem of data processing and integration into an overall intelligence picture. The quantity of data to be handled in Fleet defense will, in all probability, continue to increase at a very rapid pace, and data-processing systems will have to be developed to handle this information more rapidly and more efficiently.

In the far-advanced time period, from 15 to 50 years hence, it is possible that radiative weapons will begin to become attractive. Any serious consideration of such weapons for Fleet defense must be accompanied by significant research and study of the problem of providing adequate power, cooling, and shielding for these weapons. What constitutes adequate power is questionable, but it is probably of the order of magnitude of converting the power output of Hoover Dam to microwave energy and coherently focusing it by large distributed radiators on a 1-m² area at the target. Needless to say, such a small lethal area would require very precise tracking and aiming equipment. Other forms of energy, such as coherent infrared and gamma rays, are being investigated for lethal mechanisms with possible air-to-air applications.

Finally, the development of an effective defense against orbital weapons may well include a study of ways of neutralizing the orbiting payload without the enemy's knowledge that this has occurred. This defense concept might also involve radiative weapons technology.

Thus, within the foreseeable future, it is quite possible that the primary burden of Fleet defense will be borne by systems quite different from those available today. These systems might take the form of integrated countermeasures equipment, lethal radiative weapons, or versatile anti-sub/ship/air missile systems. There are several logical reasons for these trends in future defensive systems.

(1) The increased sophistication of future offensive weapons will broaden the spectrum of possible effective countermeasures.

(2) In order to maintain a primary capability as a limited-war striking force, the Fleet must place increasing emphasis on reservation of deck space for the attack function. As the nature of the threat continues to broaden in scope, multipurpose weapons will be required to keep the task-force space and weight available for defensive systems to a minimum.

(3) Continued reduction in available defense system response time will place unreasonable speed requirements on surface-to-air missile systems. This unreasonable requirement may ultimately be met in part through the use of lethal radiative weapons.

## Future Fleet Defense

Considering these factors, it is probable that within the next 50 years Fleet defense will be based on something like the following concept: Very early warning of an attack on Fleet units could be provided by a satellite information-gathering system. The information picked up by the satellite would be relayed to a data-processing center for world-wide secure transmission to Fleet units afloat. Early warning for specific Fleet units would be provided by a nuclear, hovering device equipped with high-resolution three-dimensional radar and stationed approximately over the task-force center (Fig. 6).

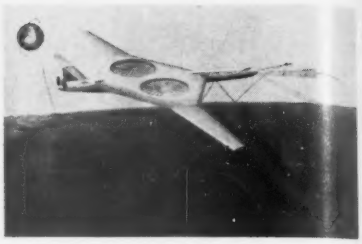


**Fig. 6. Future Fleet defense.**

Defense against high-altitude threats would be provided by a long-range homing missile system with a multiple guidance capability. This system would also have a capability against surface and underwater targets. When used as a defense against submarines, the weapon would have an active homing system for underwater guidance, supplemented by command mid-course guidance. Defense against low-altitude threats, such as subsonic low-altitude missiles, would be by electronic-countermeasure systems, supplemented by advanced-design relatively short-range missiles, and ultimately by lethal radiative weapons. Any radiative weapon defense system should be designed with a capability for intercepting ballistic missiles in the mid- to near-terminal phase.

## Conclusions

(1) Current and programed manned interceptors will prove reasonably effective against the manned-aircraft threat through 1970, or until such aircraft begin to carry long-range, high-speed air-to-surface missiles.

(2) Current and programed surface-to-air missiles should provide adequate defense against manned aircraft penetrating the outer perimeter of Fleet defense through 1970.

(3) The development of advanced guidance techniques for use with long-range surface-to-air missiles should be evaluated as a counter to high-Mach-number manned-vehicle threats of the future.

(4) Airborne early-warning aircraft should be provided with a capability for detecting submarine-launched weapons as an aid to counter these weapons as well as to help localize antisubmarine-warfare operations.

(5) Fleet air defense success in the 1970's will depend, to an increasing extent, on the capability of the airborne

early-warning aircraft and other auxiliary surveillance systems.

(6) A missile defense system to counter a supersonic, low-altitude missile threat should be studied.

(7) Threats posed by shore-based ballistic missiles and supersonic low-altitude penetrators will require the Fleet to depart from conventional early-warning concepts. Satellite surveillance will be required for both attack and defense capabilities, along with the possibility of using radiative weapons against the nuclear payloads of both ballistic missiles and the supersonic low-altitude penetrators.

(8) Defense against deorbit weapons might be ship- or shore-based systems to render enemy warheads impotent through the radiation from a near-by nuclear burst, other radiative technology, or destruction by pellets injected into the path of the orbited satellite.

✦ ✦ ✦

## Political Economist's Views (Continued from page 23)

Projection is particularly dangerous at the present time, when one of the greatest events in human history is about to occur—namely, the acquisition of laboratories of a kind we have never dreamed of before: laboratories in space. I have no doubt that their impact upon modern technology will be very great, and therefore all these projections—which, of course, are very interesting and unquestionably based on a great deal of ingenuity—will have to be taken with a large grain of salt. They may prove to have been very limited. Let me now add something about the sort of general feeling I have about the lectures which have been given here.

A great deal of confidence has been shown—a sort of confidence that in spite of the difficulties of air warfare and of difficulties with submarines, somehow we shall master them, somehow all will be improved, somehow the manned airplane is here to stay, etc. Incidentally, the functions—and how many of them—in which it is here to stay were not made clear in what we just heard. That it is here to stay is unquestionable—nobody denies that. But that is not a satisfactory, operationally useful statement. I found, in listening to these lectures, that there was exhibited much more confidence for the future than would have been shown by a group of scientists discussing the very same problems. Among scientists one encounters, rather, an atmosphere of fear and apprehension about the dreadful problems which modern developments are bringing. I have been in such meetings and these fears were justified; consequently, the confidence shown here makes me feel somewhat ill at ease, particularly since it comes at a moment when we are in as great a crisis as at present and have already suffered the first great defeat in regard to the Berlin affair—namely, the success of the Russians in cutting the city in half without our doing anything against it. I found also a certain apologetic element in regard to the use and existence of nuclear weapons. Now this has disturbed me considerably. This specific remark will lead to some more general observations which are pointed, I think, in the same direction. Arms are no good if there is no determination to use them. We can build up our armaments as far as we want, but if the spirit to use them and the knowledge of how to use them are not there, they might just as well not exist. Suddenly, it is all limited war. The limited-war problem is more important at this moment than ever, but why? It is more important because we have at the time perhaps achieved a certain superior position in the overall deterrent. The limited-war danger is a consequence of our ability to control the other, bigger danger of the thermonuclear exchange. If we come to control the limited-war danger, the conflict will be pushed more and more into the political and ideological area. And there is where we ought to be able to stand our ground. Yet this is where we are especially deficient. If you wish to read how the political elements can undermine a country in a very subtle manner, especially in regard to the nuclear situation, I recommend to you a novel by an American author named Constantine FitzGibbon which is called *When the Kissing Had to Stop*—a very good book which you can get in a paperback. It is a book of equal importance to Orwell's *1984*.

The fact that political considerations suddenly endanger the use of weapons on which we have relied heavily shows in the entire current situation. Let me give an illustration. We have heard, though in somewhat conflicting manner, that submarines cannot follow carriers, although this view is based on present submarines and present submarine and carrier speeds. We have also heard that the speed of submarines may be raised to many more knots, in which case they certainly can do more than follow. So that the question of lack of speed is not very convincing. Now suppose they follow and stay at distances of 20 miles, 50 miles, 100 miles—1, 2, 3, 10 of them. What are we going to do? Are we going to wait until they start action, or are we going to sink them? And if we are to sink them, when is this behavior proper on our part? These are political questions; they are questions not of having the weapons but, rather, of knowing what we are going to do with them. Undoubtedly, the Soviet bloc is using its influence to discredit the respectability and acceptability of certain military weapons. It is here that the political machinery is at work against us at present. This is particularly true, of course, of a troublesome problem we have: whether or not we should develop a double capability in regard to limited war, both a nuclear and a nonnuclear capability. We have been made afraid of thinking of using nuclear weapons in limited-war situations. This is exactly what the Russians want. The power would be on our side if nuclear weapons were used, but if we feel embarrassed for political reasons to use them, we are at a disadvantage, which has been described very well here in many of these talks. Incidentally, there is a possibility here of new weapon development. For example, if we do not push the neutron bomb, we may deprive ourselves of a very important weapon that could be used precisely in limited-war situations. It could be used even in jungle warfare, because of its known effects. These things point to the next matter I wish to discuss briefly and that is the new ideas of the use of the weapons systems, apart from their physical characteristics.

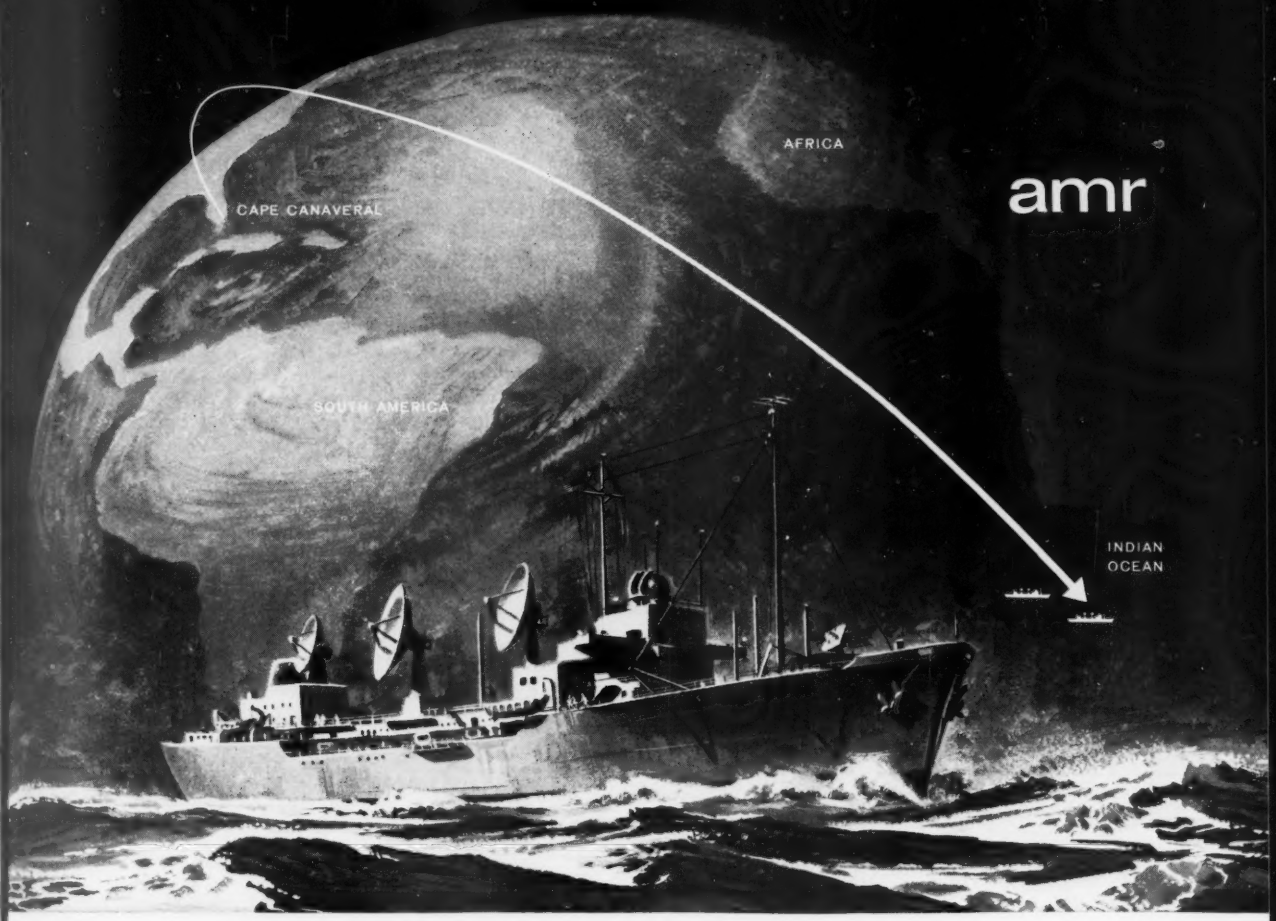
The more sophisticated a weapon system is, the greater, often, is the variety of uses to which we can put it. If you have only a club there aren't many ways of using it. And even the bow and arrow are in the same class. But bombs can already be used in many different ways; when electric countermeasures against airplanes are possible, then the problem really becomes complicated and difficult. The doors are then wide open to tremendously interesting and complicated uses. Now one speaker in his talk pointedly said that we are involved in a political chess game. This is a false analogy—it is not a chess game. Another speaker today has described the game of GO, and has given it as an illustration of a game with which one should occupy oneself. That is a nice idea, but the game is not fundamentally different from chess and it is equally inapplicable to our situation, for the

simple reason that, no matter how complicated it is in its rules, it is a game of "perfect information" in which exactly the most essential feature needed is lacking—namely, the element of bluff and the lack of information. One may even not be fully informed about oneself, as is certainly the case in situations in which command and control break down—as they always do—during battle. The analogy with GO, therefore, is wanting in realism and logical structure. It is poker which is much more similar to political and military war. Furthermore, the discussion of the problem of decision making which followed this particular observation was not, I believe, quite to the point. It was an interesting presentation of decision making in which the decision is to be optimized against nature—that is, situations, say, where no counter-player is involved. But this is not what we are playing. We have to make decisions not against nature, but against a consciously interfering adversary. There is no notion of risk applicable to this situation of military decisions when there are counter-moves. There is, then, an uncertainty of a totally different kind, and I think these problems ought to be studied and applied. It was mentioned that the Japanese played GO at their War College. But they lost the war. At the RAND Corporation they are playing what is called "Kriegspiel." This, too, is not ideal, and I wish they'd play poker instead. "Kreigspiel," as you know, is double blind chess, and it is little better than the game of perfect information. Well, all these efforts at obtaining a proper conceptual understanding of war situations and conflicts must lead away from the physical engineering type of thinking to the more abstract which is embodied in these particular operations. All this becomes applicable to the problem of identification of friend and foe and to the problem of what to do with decoys, whether decoys in submarine or ICBM warfare. There was virtually no mention of this, although it would be easy to think of artificial noises made by many devices, even by submarines. The amount of complication we can produce in the ocean is enormous, but I am sure the analyses which we have heard have not considered them and probably cannot consider them if they are carried on in their too limited manner. Regarding sounds in the ocean, one speaker said we must change our search attitude. By that he meant we shouldn't look from spot to spot, but should sample. That is a good but modest change. Totally different notions have, of course, to be introduced in this area and this again leads straight to problems which are dealt with by games of strategy.

We heard the capabilities of the Russians—to speculate a moment more—estimated to an incredible extent. It has been argued here that by about 1980, the Russians will have about 500 nuclear-powered submarines, phasing out the present ones and building up the others. Now I have high respect for the resilience of a modern economy, but that the Russians could produce 500 nuclear-powered submarines of the Polaris type in such a short time is somewhat doubtful considering the other efforts they also have to make. Be that as it may, it leads me to a criticism of another argument which was made by somebody else—namely, the argument that in submarine warfare we must strike at the sources of the submarines. I contend that if the Soviet Union were to have 500 nuclear-powered submarines, of which maybe 300 or more would actually be operating on the high seas, a strike at their bases would be completely pointless: the power represented by the submarines actually at sea and properly armed would be all that would ever be necessary for the accomplishment of their ballistic-missile mission. The time-phasing of these two different operations—their destruction of targets in America and our destruction of their bases—is completely out of joint. So I think we should look carefully at further such incompatibilities which have come up and which are, of course, inevitable. After all, they were made not by one and the same speaker, but by several; nobody is at fault, because it is here that we must have different conceptual approaches. Regarding the latter, I think it was very fruitful at least to have brought up a topic which has been very much neglected in military thinking—namely, the problem of military worth.

What is the worth of a weapon system? How can we discover it? And how can we compare the worth of different weapon systems? These are very tough problems. The presentation dealing with these matters was interesting and has a bearing on a limited field, but it does not really solve the general problem. This is to be expected; it is a long job, but if we succeed in establishing a method for determining the worth of different weapon systems, we will, I think, also make an interesting discovery—namely, the discovery that weapon systems probably do not present an Archimedean ordering. An Archimedean ordering, as you know, is, for example, given in our number system: if you have a large number and a small one, you can simply add the smaller number as many times as is necessary to reach the large number. But you will always reach it. A non-Archimedean ordering means that the differences between numbers are infinite. In other words, they fall completely apart. Applying this to weapons systems, it means that no matter how much you improve a plane, it will never turn into a missile; no matter how much you speed up a vehicle on earth, it will never turn into a plane. This is the sort of difference—it is a difference in kind. Differences in kind demand differences in treatment; they demand new ideas. May I also point out the impossibility of what one speaker advocated—namely, "the best job at the least cost"?

I would like to say a word about another most interesting talk, dealing with the growth craze and with growth comparisons and their implications. Now we hear a great deal about the annual growth rate—the United States has, say, 2.8 percent, the Russians have 3.2. Consequently, we must raise ours, and so on. For a long time I have been a student of the quality and character of economic data. I have written a book, *On the Accuracy of Economic Observations*, and am rewriting it now after ten years. I can assure you these figures are impossibly "accurate." It is impossible to set down such rates with such alleged precision. That is one thing. I will not waste time on it. The second is that even if those figures were accurate, there is another question—that of their meaning. And what growth do we want? I think we should not construct a mere growth index, but a *power* index. By this I mean that growth of our kind of life—more cars, swimming pools, bowling alleys, etc.—is not going to increase our power, while the growth of another kind of life—in further development, further military buildup, and investment in machine tools made on the other side—changes the balance of power enormously. And about this we get no information from merely hearing about the overall growth rates. Too many people are satisfied with this aspect of standards of living, and say that Russia will not soon surpass us. I don't care if they do, and eat more butter than we do, and as a consequence get more cholesterol than we have. This business of growth rates deserves a very different kind of analysis, but time does not permit me to elaborate. I think that in regard to the *power* of the two countries we must be extremely careful not to fool ourselves. If you look at what I call power rates—which, of course, also have limited accuracy—then the picture is much worse than if you look only at growth rates. Much worse, indeed. The spread of technology throughout the world is already producing results of a very peculiar nature. I will give just one illustration. The British Steel Institute, or the Association of Steel Manufacturers in Britain, last year ordered the translation of a two-volume work on steel-making from the Chinese in order




Objective: increase capability of the Atlantic Missile Range – sponsored by the Missile Test Center of the Air Force Systems Command – to study missiles and space vehicles during the critical terminal phase of flight with a refinement never before possible. Prime requisite: *mobility* . . . ability to move to the most advantageous position in thousands of miles of ocean.

The answer: conversion of two large troop transports into Mobile Atlantic Range Stations, seagoing laboratories incorporating every proven technique of instrumentation, data acquisition, and instantaneous data transmission to Cape Canaveral, integrated with the most sophisticated long range tracking radars. System Manager: The Sperry Rand Systems Group. General Offices: Great Neck, N. Y.

The Mobile Atlantic Range Stations will be equipped with integrated radar, telemetry, infrared tracking, data handling, communications, inertial navigation, and sophisticated weather forecasting. Team members include Bethlehem Shipbuilding, Ford Instrument, Gibbs & Cox, IT&T, Remington Rand UNIVAC, Sperry Gyroscope Company.

SPERRY

that the British steel industry should be able to produce steel of the high quality which the Chinese are producing in some of their mills. Well, now, that gives us an idea of what is coming. And all this in spite of the famine and the other troubles the Chinese have! It is also known that one of the best students in rocket research which MIT ever had was a Chinese who wanted desperately to stay in this country and who, of course, was expelled by the immigration authorities. He is now in charge of rocket development in China. What will the consequences be? Thus, the vital information developed in one country is easily disseminated to other countries.

The prospects, therefore, for further complications all over the world are tremendous. Then there is the "N-country" problem—that is to say, the spread of nuclear weapons, which is undoubtedly coming very rapidly. I mean a different spread, of course, than a mere distribution of nuclear weapons within the same alliance. I am thinking, rather, of somebody outside the alliances, such as China, getting them. Finally we have with us, whatever else we do, whether or not people get killed in wars in large numbers, the population explosion to which reference has been made. It is an event of such magnitude and so definitely with us that it is absolutely safe to predict that it will cause further trouble in the world.

✦ ✦ ✦

## Control of GEM's (Continued from page 29)

by a series of labyrinth or recirculating ducts. The annular-jet machine has received the largest proportion of development efforts. The recirculating machines appear to offer savings in required power, at the expense of increased complexity.

The third configuration of ground effect vehicles is the ram wing. The ram wing depends on a forward motion for its lift. By operating very close to the ground, induced drag is reduced and lift is increased.

Much of this discussion will be confined to the annular-jet GEM because of the attention it has received. The theory of the annular jet in ground effect is derived in a straightforward manner from momentum theory, and considers the pressure under the vehicle to be balanced by the centrifugal force required to turn the jet between the nozzle and the ground. This force, and therefore the sustainable base pressure, is a function of the operating height and the angle of the jet exhausting from the nozzle. Much has been said about the so-called augmentation factor, which is simply the ratio of the lift obtained by the system in ground effect to that obtained in free air. In order that a ground effect machine may offer power savings, this augmentation factor must obviously be greater than one. Based on theory developed by Chaplin, operating heights less than 20 percent of the base diameter allow a reduction in lift power requirements from that required in free air.

Since marginal power improvements will not overcome the lack of free-flight capability of the ground effect machine, useful operating heights must be *considerably* less than 20 percent. In this respect, the balance of minimum power against minimum height for obstacle clearance compromises operating heights to about 5–10 percent of the effective base diameter. For example, at an operating height of 5 percent of the base diameter, the power required to lift the vehicle is one-fourth the power required in free air. *The ratio of operating height to effective base diameter is basic to power requirements and to the operating capability of the vehicles. It* is symbolized by $h/D$. This parameter will be used throughout the analysis.

It can be shown from the basic momentum theory, and confirmed by experiment, that the power required for lifting a vehicle is *proportional to the gross weight to the three-halves power* ($W^{3/2}$) *and inversely proportional to the base area to the one-half power* ($S^{1/2}$). This function is dependent directly on the height, as previously mentioned, and to a lesser extent on the planform shape. The planform loading symbol $W/S$ is defined as the gross weight divided by the effective base area. This also is an important parameter, and has a direct effect on power requirements.

With these basic relations in mind, the control aspects can be developed as indicated in the next section.

### Stability and Control

Stability and control are readily recognized as major areas of concern for the GEM. Fortunately, the analytical techniques developed for aircraft and submarines are available for application to the GEM configuration. Initial analysis uses the basic parameters common to any three-dimensional object in motion. They are as follows.

(1) GEM motion can be described in terms of the conventional six degrees of freedom.

(2) GEM's have the universal characteristics of inertia about all axes.

(3) Interaction with the fluid medium in which the GEM is submersed provides significant external forces, particularly with respect to ground proximity.

Chaplin's early work used a simple model to explain lift augmentation due to creation of the air bubble underneath the vehicle. As laboratory methods were developed, model tests by various people produced data which suggested improvements in analysis. The present state-of-the-art in GEM stability and control work may be summarized as follows.

(1) Analytic work has proceeded generally in the direction of removing simplifying assumptions. As the resultant equations become more complex, their solutions become more realistic in the sense of predicting observed (model) performance.

(2) Model work has provided insight into performance characteristics anticipated in full-size vehicles, particularly where water patterns are used to study vortex distortion.

(3) Full-scale tests have been limited. However, captive vehicle tests over corrugated terrain have been very useful in study of GEM dynamics.

A quick comparison of major control phenomena for the GEM with those of more familiar vehicles helps to identify the stability and control aspects of anticipated GEM performance.

(1) In comparison with *airborne vehicles*, the GEM cannot bank to any degree to aid in maneuvering. It does have the unique characteristic of inherent vertical static stability and can, of course, hover. With the anticipated range of forward speeds, aerodynamic control forces will be relatively small.

(2) In comparison with *landborne vehicles*, the GEM does not have the inherent roll and pitch stability of four-point suspension. On the other hand, for equal power plants and inertias, the GEM has greater acceleration capabilities and can rotate on its own axis relatively unhindered.

(3) In comparison with *waterborne vehicles*, the GEM misses the sometimes useful drag characteristics of the water medium. By the same token, the GEM's ability to rotate on its axis rapidly, especially at zero forward speed, provides a unique situation for maneuvering.

### Altitude Stability

A specific analysis of the inherent stability and control requirements of the annular-jet GEM is presented in the following paragraphs. The annular-jet design has been selected because it represents the majority of the concepts being proposed.

For a circular (or near circular) planform, the continuous annular-jet GEM can be represented in hover by a mass supported by nonlinear springs and dashpots. At zero pitch and roll angles, the vertical equation of motion for small perturbations is:

$$M(d^2h/dt^2) + B(dh/dt) + K(h - h_0) = F(t)$$

where

$h$ = base height
$h_0$ = equilibrium height
$M$ = vehicle mass
$B$ = a linearized damping parameter
$K$ = a linearized spring parameter
$F(t)$ = a forcing function

The relative stability of this motion can be observed with $F(t) = 0$ and with the disturbance being an initial offset. The two parameters of importance in the solution are $\omega_n$, the undamped natural frequency, and $\zeta$, the damping coefficient.

Both analytic work and limited tests on models indicate that the motion will be underdamped. Therefore, $\omega_n$ is of paramount importance in understanding the motion of the GEM. It is given by the relation

$$\omega_n = \sqrt{\frac{K}{M}} = \sqrt{\frac{-\partial L/\partial h}{L/g}} \quad \Big| \quad h = h_0$$

$K$ is defined by the rate of change of lift with respect to height around the equilibrium height. Lift, $L$, is determined by the jet momentum, $J$, and the augmentation of lift due to the contained air bubble,

$$L = J\{\cos\theta + [(1 - \sin\theta)/(2h/r_0)]\}$$

where $\theta$ is the jet angle measured from the vertical and $r_0$ is the radius of the vehicle base. It can be shown that $J$ may be expected to remain constant for small perturbations. $\theta$ will be set at an optimum value for the equilibrium height.

$$K = -(\partial L/\partial h) = [J\, r_0(1 - \sin\theta)]/2h^2$$

Static vertical stability is assured (except for the theoretical case of $\theta = +90°$) for the simplified model.

At the present state-of-the-art, optimum $\theta$ will be between $-30°$ and $-90°$. Furthermore, $r_0$ will be five to ten times $h_0$. Thus,

$$\partial L/\partial h \approx -(L/h)^*$$

which leads to the simple equation,

$$\omega_n = \sqrt{g/h_0}$$

The critical parameter then becomes the damping coefficient, $\zeta$, evaluated from

$$2\zeta\,\omega_n = B/M$$

There will be only feeble drag at the low oscillating frequency and amplitude. Therefore, the damping forces of significance must arise from compression, expansion, and air movement within the air curtain.

The simplified model employing only momentum considerations provides an optimistic picture of conditions under the vehicle. A more sophisticated model including viscous (mixing) effects and considering the vortex and its displacement is not yet available. As a first approximation, the damping due to air displacement was calculated under the simplifying assumption of the vehicle remaining in balance—that is, the cancelling of two opposite effects. As an example, when the height of the vehicle increases, (1) the jet stream will tend to lift off earth contact, and (2) the bubble pressure will decrease, opening up jet curvature. If these factors cancel, the vehicle remains in balance during its excursion and the jet streams remain tangential to the ground.

Three annular jets were considered under the following conditions: (1) a constant loading of 40 lb/ft², (2) a circular planform of radius $r_0$, (3) $h_0 = 0.1\, r_0$, and (4) $G$ (jet width) $= 0.25\, h_0$.

The three designs resulted in the calculated natural frequencies and damping coefficients for vertical motion shown in Table 1. These damping coefficients are very low, but positive, and thus indicate an inherently stable machine.

As noted, the basis for these considerations has been the simplified model which ignores viscous effects. The use of a viscous model predicts an augmentation versus altitude curve which is closer to that found experimentally. As shown in Fig. 3, the actual augmentation is less than that predicted by either model. The slope of the curve ($K$) is important for dynamic considerations. Apparently, because of the vortex action, the slope will change as follows.

(1) $h/D < 0.1$: for the models tested, the slope is negative and inversely proportional to height; the model is stable.

(2) $h/D$ 0.2 to 0.3: for the models tested, the slope is about zero; the model has neutral stability.

(3) $h/D$ 0.4 to 0.6: for the models tested, the slope is positive and relatively constant; the model is unstable.

(4) $h/D > 0.8$: for the models tested, the slope becomes negative again.

The significance is clear. If the GEM is elevated, a region of neutral stability will be reached beyond which the GEM will be thrown into a self-sustained vertical oscillation. In the absence of knowledge regarding the vortex dynamic effects, it can only be predicted that such oscillation will build to a steady-state amplitude between the two regions of stability as in a conventional limit cycle.

* For the derivation of this equation, see Appendix, p. 54.

**Table 1**

| $r_0$ | $\omega_n$ | $\zeta$ |
|---|---|---|
| 50 ft | $\sqrt{0.2g}$ rad/sec | 0.07 |
| 10 ft | $\sqrt{1.0g}$ rad/sec | 0.03 |
| 2 ft | $\sqrt{5.0g}$ rad/sec | 0.013 |

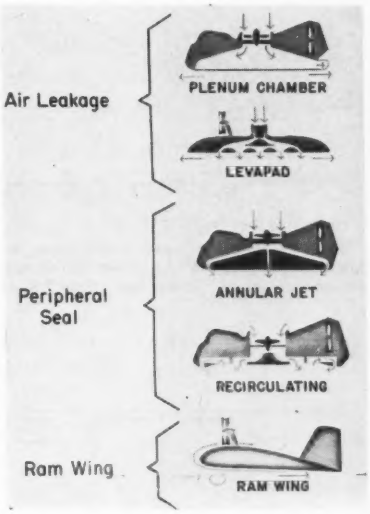



Fig. 2. GEM principles. (From Ref. 2)

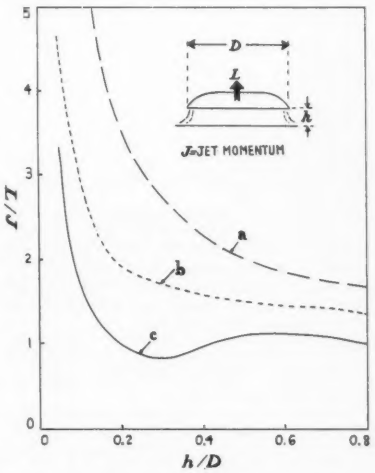



Fig. 3. Zero-velocity lift characteristics: (a) theoretical (nonmixing); (b) theoretical (with mixing); (c) experimental. (From Ref. 3)

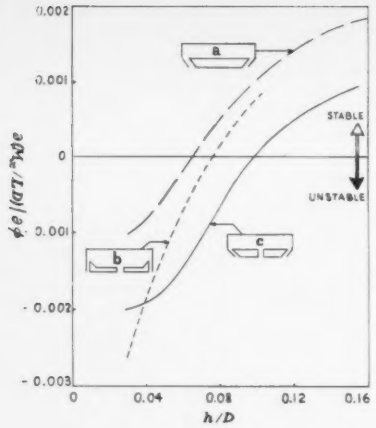



Fig. 4. Effect of base configuration on lateral stability: (a) 45° jet, no slot; (b) vertical jet with slot; (c) 45° jet with slot. (From Ref. 4)

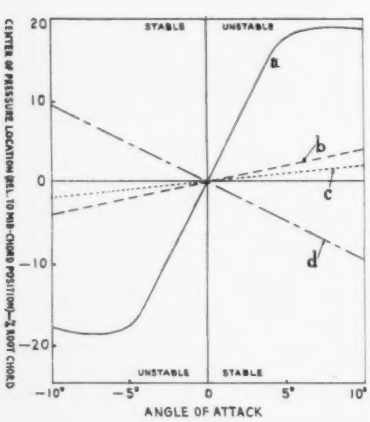



Fig. 5. Static stability with vertical and inward jets: (a) vertical jets at critical height; (b) vertical jets near ground; (c) inward jets near ground; (d) inward jets with central jet near ground. (From Ref. 5)

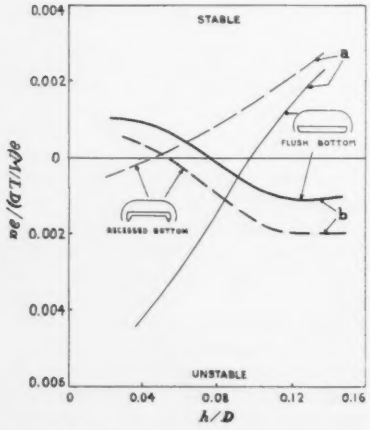



Fig. 6. Stability characteristics (a) over land, and (b) over water. (From Ref. 7)

## Roll, Pitch, and Yaw Stability

In the simplified model at least, the annular jet (and the plenum-chamber design as well) has no inherent roll or pitch stability. Actually, a rate of roll or pitch would give rise to a return moment due to jet momentum considerations. However, at the expected low oscillating frequencies and amplitudes, this should be negligible (although of stable sign). With respect to yaw, however, there is no spring return. Thus, the damping contribution from this effect is significant.

A rate of yaw will produce a moment proportional to the jet mass flow and the square of the GEM radius. Thus, the yaw equation of motion would be similar to

$$I_y \frac{d^2\psi}{dt^2} + \rho S_j V_j r_0^2 \frac{d\psi}{dt} = N(t)$$

where

$I_y$ = rotational inertia about the yaw axis
$\psi$ = the yaw angle
$\rho$ = density of air
$S_j$ = jet area
$V_j$ = jet velocity
$r_0$ = radius of GEM
$N(t)$ = a disturbance torque

This equation exhibits neutral stability.

Returning to roll and pitch, the lack of inherent stability has led investigators to employ internal slots, dividing the base into (more or less isolated) compartments. Each compartment then provides the positive vertical stability of an individual annular jet. The various compartments combine to provide roll and pitch stability.

The rotational spring constant has been shown experimentally by tests at David Taylor Model Basin to be of the form

$$K_r = C_1/h_0$$

where $C_1$ is a geometric constant. Thus the equation of motion of roll is:

$$I_r(d^2\phi/dt^2) + B_r(d\phi/dt) + K_r\phi = N(t)$$

from which the undamped resonant frequency is:

$$\omega_n = C_2\sqrt{g/h_0}$$

where

$$C_2 = \sqrt{C_1/M\bar{r}^2}$$

$M$ being the mass of the GEM and $\bar{r}$ its radius of gyration about the roll axis.

The simplified model gives no clues as to significant damping forces. Conventional drag is again unimportant at these velocities. The bubble is not compressed or expanded but rather shifted from side to side. A series of tests by DTMB over sinusoidal ground patterns gives some clue as to the damping available. With the "disturbance" amplitude-to-wavelength ratio maintained at 0.01, and the vehicle length-to-wavelength ratio at 0.417, a peak amplification of about 3.2 in the pitch motion was measured at resonance for a model 7 ft long.

A factor of 3.2 corresponds to $\zeta = 0.15$ in the standard quadratic form. If the individual compartments were assumed to remain isolated during roll, a damping factor somewhat less than this would be predicted. Clearly, the question of the source of damping forces must be examined.

There is an unpredicted shift from stable to unstable static-roll correction moments above a critical height. This is apparently due to the nonagreement between available mathematical models and experimental measurements with respect to the lift versus altitude curve at higher values of $h/r_0$. As shown in Fig. 4, the center of pressure shift when a roll altitude is assumed is in a negative—i.e., stable—direction at low height-to-diameter ratios. The restoring moment ($M_x$) is made nondimensional by dividing by the lift times the effective base diameter $D$. It is noted that the crossover altitude is a function of jet angle and the use of interior slots for an otherwise identical GEM.

An alternate picture of the effects of configuration and altitude on static stability is shown in Fig. 5. Here the resultant center of pressure location (relative to mid-chord position) is plotted against angle of attack for four combinations: (a) a vertical-jet GEM, having no interior slots, at critical height; (b) the same, near the ground; (c) a GEM having inward-directed jets, but no interior slots, near the ground; and (d) the same as (c), with a central jet.

The dynamics can generally be characterized by stable, but highly underdamped, operation at heights below 0.1 diameter. Furthermore, there are saturation tendencies which would tend to cause limit cycles in unstable regions and therefore prevent run-away oscillation.

For vertical motion this limitation is provided by the stable operating regions surrounding the unstable zone. In roll and pitch, the physical limitation of ground contact provides the necessary saturation, at the low height/diameter ratios which are of interest for GEM's.

Stability over water has been shown experimentally to be quite different from that over land. As shown in Fig. 6, there was an almost 180° reversal of stability slope characteristics for a particular design. No analytic prediction of this effect has been uncovered.

Below the hump speed, stability over water is less than over land, and the moment of the craft due to momentum drag would cause a larger change of nose-up trim, consequently causing an in-

crease in drag. This drag could be reduced by ballasting the machine forward in order to trim it more nose-down, but in this case the machine would then have a very nose-down aspect when operating over land, which would result in a reduction of clearance height. It would not, furthermore, be very practical constantly to be changing the ballast of an amphibious machine as it went from water to land and vice versa. However, it is felt that this could be achieved by suitable trimming devices, paid for at a rise in system complexity and some loss in performance. As a general design figure, it has been estimated that an adequate trim control or stability to allow for operation over both land and water causes a loss of as much as 15–25 percent of performance.

Very little has been done to date to investigate the effect of forward speed on stability. Two opposing effects are noted. A forward shift of the center of pressure is predicted (and experimentally uncovered) because of the nose-up moment arising from inlet momentum drag at increased forward speed. At the same time, forward velocity increases the base pressure under the aft end of the GEM (presumably due to the jet-flap effect of the jet curtain). This then is a nose-down moment. In one series of tests with a 42-in.-diameter free GEM, the nose-up moment strongly predominated.

From all the tests that have been performed by Saunders-Roe on various models and on the SRN-1, the practical stability requirement is that the center of pressure shift per degree should be approximately 1 percent and should not be lower than 0.5 percent. This means that the payload, which is of the order of 30 percent of the gross weight, must be accurately located to within 3 percent of the craft length, since the usable space on the craft is of the order of half its length. This effectively allows a 5 or 6 percent error in positioning the payload.

It is interesting to note that in none of the tests Saunders-Roe have done have they managed to get an adequate degree of stability at height/diameter ratios of more than 0.06, though on some two-dimensional tests they have achieved this up to 0.1 $h/d$.

Because of the difficulty of obtaining the adequate degree of stability, it is absolutely essential to keep the c.g. as low as possible.

### Controls

The control system used to maintain the desired operating height and vehicle attitude must be designed to match the peculiar situation of the GEM. It appears advantageous to combine this control system with the required maneuvering controls.

Very little work has been accomplished


*Increased technical responsibilities in the field of range measurements have required the creation of new positions at the Lincoln Laboratory. We invite inquiries from senior members of the scientific community interested in participating with us in solving problems of the greatest urgency in the defense of the nation.*

RADIO PHYSICS and ASTRONOMY

RE-ENTRY PHYSICS

PENETRATION AIDS DEVELOPMENT

TARGET IDENTIFICATION RESEARCH

SYSTEMS:
Space Surveillance
Strategic Communications
Integrated Data Networks

NEW RADAR TECHNIQUES

SYSTEM ANALYSIS

COMMUNICATIONS:
Techniques • Psychology • Theory

INFORMATION PROCESSING

SOLID STATE
Physics, Chemistry, and Metallurgy

• *A more complete description of the Laboratory's work will be sent to you upon request.*

All qualified applicants will receive consideration for employment without regard to race, creed, color or national origin.

Research and Development
LINCOLN LABORATORY
Massachusetts Institute of Technology
BOX 23
LEXINGTON 73, MASSACHUSETTS

in the area of GEM controls, and no conclusive results are yet available. Because of the low damping in vertical motion, and the negligible damping in pitch and roll, careful consideration must be given to a control system augmenting the capabilities of the human operator.

For example, it might be necessary to provide a mass-shifting device for trimming during flight, as is done in a submarine. If the operational GEM vehicle is of appreciable size, which favors reduced power requirements, then the cost of instrumentation for automatic roll and pitch control becomes proportionally less.

In contrast to other GEM characteristics (power required and stability), control effectiveness may be expected to decrease at decreased operating height. This is true because the jet momentum required to maintain a given lift is reduced as the vehicle base height decreases. Thus, control systems based on the alteration of the jet stream will have a reduced momentum supply unless particular attention is given to this interaction.

## Conclusion

Adequate stability and control derivatives necessary to the design of ground effect machines, particularly those performing outside a 10 percent $h/D$ ratio, are required for a wide range of vehicles and lift systems. Data are required for the pitch, yaw, and roll moments anticipated for plenum, annular jet, recirculation, and dynamic-lift ground effect machines. Such data should be presented nondimensionally to cover the effects of size, speed, and various c.g. locations.

Much work remains before control systems can be successfully applied to the GEM. In general, it can be seen that the GEM represents a highly underdamped and marginally stable process in present configurations. Aside from considerations of power requirements, the lack of stability at higher altitudes is a major limitation. Here is a clear situation where control development must occur *during* the evolution of a new process.

## Appendix

The equation $\partial L/\partial h \approx -(L/h)$ is derived as follows. From the equation for lift,

$$L = J(\cos\theta + \{[r_0(1 - \sin\theta)]/2h\})$$

we obtain

$$\partial L/\partial h = (-1/h)\ (L - J\cos\theta)$$

as $\theta \rightarrow -90°$ and/or $L \gg J\cos\theta$,

$$\partial L/\partial h \approx -(L/h)$$

As can be seen in Fig. 3, as $h/D$ increases, the assumption of $L$ large with respect to $J\cos\theta$ becomes questionable. However, for preliminary analysis the simplification provides some prediction of the spring effect.

## References


[1] *Proceedings of the Symposium on Ground Effect Phenomena*, Princeton University, Princeton, N.J., Oct. 21–23, 1959.

[2] *The Ground Effect Machine—Technical Aspects, Operational Characteristics, and Evaluation Parameters*, BAARINC Rep. TRO 60-6, Booz-Allen Applied Research, Inc., Bethesda, Md., Aug. 1960.

[3] Poisson-Quinton, P., "Two-Dimensional Studies of a Ground-Effect Platform," *Proceedings of the Symposium on Ground Effect Phenomena*, Princeton Univ., Princeton, N.J., Oct. 21–23, 1959.

[4] Kuhn, R. E., and Carter, A. W., "Research Related to Ground Effect Machine," *Proceedings of the Symposium on Ground Effect Phenomena*, Princeton University, Princeton, N.J., Oct. 21–23, 1959.

[5] Frost, J. C. M., and Earl, T. O., "Flow Phenomena of the Focussed Annular Jet," *Proceedings of the Symposium on Ground Effect Phenomena*, Princeton University, Princeton, N.J., Oct. 21–23, 1959.

[6] Fielding, P. G., *Performance Nomograms for GEM's*, AEROSPACE ENGINEERING, Vol. 20, No. 8, pp. 10–11, 67–70, Aug. 1961.

[7] Kuhn, R. E., Carter, A. W., and Schade, R. O., *Over-Water Aspects of Ground Effect Vehicles*, IAS Paper No. 60-14, Jan. 25–27, 1960.



## The IAS Library

Publications treated in *International Aerospace Abstracts* are maintained by the Library for use by the IAS Membership. They are *not* for sale but are made available through the facilities of the Library.

LENDING SERVICES: Institute members, both Individual and Corporate, may borrow periodicals, reports, and books for a period of 2 weeks, excluding time in transit. Excepted are certain reference books and those IAS publications that may be purchased.

PHOTOCOPY SERVICES: The Library is equipped to provide, as a service, positive photocopies of certain materials in its collections. Rates on request.

For detailed information about these and other services, write to:

*John J. Glennon, Manager*
*Technical Information Service*
*Institute of the Aerospace Sciences, Inc.*
*2 East 64th Street*
*New York 21, New York*

## Tensile Instability (Continued from page 33)

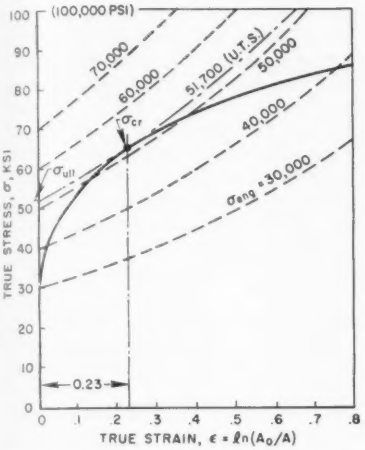



Fig. 3. Curves of constant load or engineering stress.

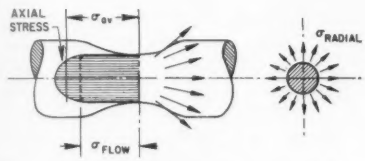



Fig. 4. Stress distribution in neck. (Based on Figs. 8–12 of Ref. 1)

$$d\sigma_{tr}/d\epsilon_{eng} = \sigma_{tr}/(1 + \epsilon_{eng}) = \sigma_{eng} \quad (11)$$

Since the maximum value of $\sigma_{eng}$ is called the ultimate tensile stress we may write

$$E_{tcr} = (d\sigma_{tr}/d\epsilon_{eng})_{cr} = \sigma_{ult} \quad (12)$$

The graphical method of locating the critical point is shown in Fig. 2.

If the true stress-strain diagram has a shape such as that of Fig. 1 or Fig. 2, the load will drop off after reaching its maximum value. This represents a form of *load instability*, similar to that of a column. If such a tension member is subjected to a load that must remain substantially constant—e.g., a dead weight—static equilibrium cannot be maintained and a rapid extension of the member will occur, ending in actual material failure.

The foregoing methods of determining the maximum load contain nothing which will indicate whether the extension will occur uniformly over the whole length, or will localize in the form of a neck. For the stress-strain diagram shown in Fig. 1, the load would drop off after reaching its maximum value, *even if no necking were to occur*. We know, however, that a neck will actually begin to form at about the same time that the load reaches a maximum. This limits the uniform elongation to the value corresponding to the ultimate tensile stress, even though the potential elongation (over a short gage length) may be much higher. This is indicated in Figs. 1 and 2. Although it is usually assumed that necking will begin when the ultimate tensile stress is reached, the foregoing methods do not constitute a theory of necking, or *geometric instability*.

### Geometric Instability

One way to attack instability problems is to imagine the phenomenon to occur and, by doing so, to discover what prevents it from occurring. We shall therefore imagine that an initially straight specimen develops a neck at a constant value of load, sometime before the maximum load is reached. The assumption of constant load establishes a relationship between true stress and true strain as follows.

$$\sigma_{i_{tr}} = \left.\frac{P_i}{A}\right|_{P_i = \text{const}}$$

From the definition of true strain, Eq. (6),

$$A = A_0 e^{-\epsilon}$$

Substituting in the first of the foregoing two equations,

$$\sigma_{i_{tr}} = \left.\frac{P_i}{A_0} e^{\epsilon_{tr}} = \sigma_{i_{eng}} e^{\epsilon_{tr}}\right|_{\sigma_{i_{eng}} = \text{const}} \quad (13)$$

A family of curves representing various values of constant load (in terms of engineering stress) is shown in Fig. 3.

The slope of a constant load curve at a point represented by $\sigma_{tr}$ is

$$d\sigma_{tr}/d\epsilon_{tr} = \sigma_{i_{eng}} e^{\epsilon_{tr}} = \sigma_{tr} \quad (14)$$

This is identical in form with Eq. (9) for the critical slope. Eq. (9) may therefore be interpreted as locating the point at which the true stress-strain diagram becomes tangent to one of the constant load curves, as shown in Fig. 3. (The corresponding ultimate tensile stress can be read directly from the intersection of the latter curve with the ordinate at $\epsilon = 0$. For the material shown, it is 51,700 psi.)

If necking at constant load were to begin at some stress below $\sigma_{cr}$, the stress-strain diagram would have to follow the constant load curve through that point. Fig. 3 shows that the slope of the stress-strain diagram always exceeds that of the constant load lines crossing it, below the stress $\sigma_{cr}$, consequently necking is not possible below this stress. But this statement applies equally well to a specimen that would elongate without necking. This shows that it is meaningless to state that necking is prevented by strain-hardening.

There is an additional effect produced by necking. If we imagine the force to be transmitted along "streamlines" of constant force, the curvature of such lines will cause outward-acting tensile stresses in the root of the neck, as indicated in Fig. 4. Such radial stresses reduce the shear stresses, since the maximum shear stress is half the difference between the two principal stresses (axial and radial).

Bridgman[2] has shown experimentally that the local plastic strain (in cylindrical specimens) is substantially constant across the neck. He assumed that, as a consequence, the shear-stress distribution across the neck must be uniform. For constant shear stress, the longitudinal stresses must increase by the value of the radial stress, which builds up from zero at the surface to a maximum at the center. The resulting nonuniform axial-stress distribution is illustrated schematically in Fig. 4. The factor by which the average true stress is increased (beyond that for a straight


Immediate Opening for AERODYNAMICIST

Desire Engineering Graduate with experience in rotary wing/VTOL performance, and stability and control analysis. Must be creative. Position involves difficult technical analysis for our expanding research programs.

Submit personal resume to:

**Engineering Personnel Manager**
**BELL HELICOPTER COMPANY**
**P. O. BOX 482**
**FORT WORTH 1, TEXAS**

"An Equal Opportunity Employer"

(Bell Helicopter Company is a Division of Bell Aerospace Corporation, A Textron Company)

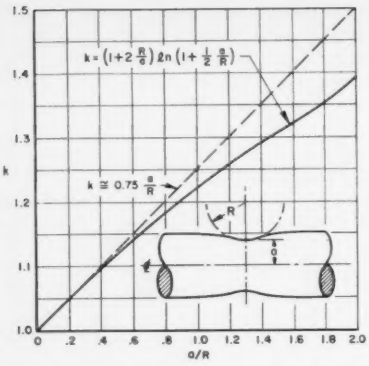



Fig. 5. Constraint factor. (From Bridgman[2])

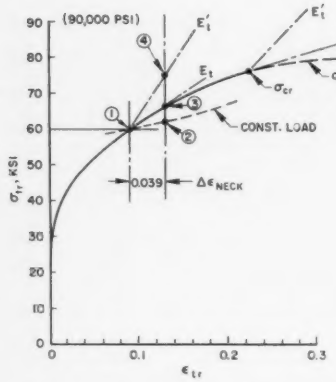



Fig. 6. Geometric effect of a shallow neck.

specimen having the same shear stresses) was calculated by Bridgman. It can be put in the following form

$$k = \sigma_{avg}/\sigma_{flow} = [1 + 2(R/a)] \times ln\,[1 + {}^1/_2(a/R)] \quad (15)$$

where

- $k$ = constraint factor (term introduced by Bridgman)
- $\sigma$ = average longitudinal (true) stress at root of neck = $P/A$
- $\sigma_{flow}$ = true stress that would have been obtained if there had been no necking (assumed by Bridgman to be the true stress at surface, at root of neck)
- $R$ = radius of osculating circle at root of neck (Fig. 4)
- $a$ = cross-sectional radius at root of neck

The relationship between $k$ and $a/R$ is shown in Fig. 5. We shall use this formula to work out some values in a particular case, with the understanding that we are not interested in numerical values as such, but rather in clarifying the mechanism of geometric stability.

Let us assume, for example, that a specimen has the true-stress true-strain curve of Fig. 6 and that it has been pulled to a true stress $\sigma_1$ of 60,000 psi (Point 1) at which point the load is held constant. Assume also that at this point the diameter is 0.50 in. Now imagine a shallow neck to be developed, *while under constant load*. The depth of neck has arbitrarily been chosen as 0.005 in. and the radius $R$ is taken as 0.50 in. The area ratio $A_1/A = 1.04$ and the local true strain increment required to produce the neck is therefore

$$\Delta\epsilon = ln\,(A_1/A) = ln\,1.04 = 0.039$$

The stress actually required to produce this increase in strain (neglecting radial effects) is found from the stress-strain diagram to be 67,000 psi (Point 3). But the true stress at the root of the neck is only $1.04 \times 60{,}000 = 62{,}400$ psi. (This is indicated by Point 2, which falls on the constant load line.) Therefore, continued plastic strain at constant load is impossible, either by necking or by uniform elongation. (Time effects are assumed to be negligible.)

Now consider the additional geometrical effect of the neck. In Fig. 6 the minimum root radius ($a$) is $0.250 - 0.005 = 0.245$ in. and $a/R = 0.245/0.50 = 0.5$ (approximately). From Eq. (15) or Fig. 5 the constraint factor is found to be $k = 1.12$. *This means that the true stress must be 12 percent greater in the necked specimen than in the unnecked specimen to produce the required plastic strain.* Therefore an average stress of $1.12 \times 67{,}000 = 75{,}000$ psi is required. This is indicated in Fig. 6 by Point 4. *The effective tangent modulus ($E'_t$) of the stress-strain diagram is increased by the geometrical effect of the neck.* This represents an additional stabilizing factor, beyond that of strain-hardening.

We now move to the point at which the stress-strain diagram has the critical slope—i.e., the point where the load becomes a maximum, shown also in Fig. 6. If uniform elongation (no necking) were to continue beyond this point the resulting stress-strain diagram would represent the "flow" stress—that is, it would be unaffected by the geometry of the neck. This curve is shown by a dashed line in Fig. 6.

If a neck were to begin to form at the critical point, the effective slope at that point would become greater, as indicated by the line labeled $E'_t$. We must therefore conclude that a neck cannot form spontaneously at the instant when the critical stress is reached. However, as the strain is further increased, the specimen may *begin* to neck down in a progressive manner.

This phenomenon may be called, as in column theory, a bifurcation of equilibrium configurations. The idealized specimen has a choice of continuing to elongate uniformly or of beginning the formation of a neck. If, however, the flow stress-strain diagram should coincide with the curve for constant load, no necking is possible because the required $E'_t$ could not be developed without an increase in load. *This explains why a material can have a flat-topped engineering stress-strain diagram and still develop a large value of uniform elongation.* If necking were governed only by the maximum load criterion, as usually stated, such behavior would be impossible; the specimen would start to neck as soon as the ultimate tensile stress is attained. This is clearly shown by the true-stress engineering-strain diagram for an ideally plastic material, as in Fig. 7. In this special case, the maximum load and the critical slope are reached at the very beginning. According to the classical interpretation, a neck would start to form as soon as the stress reached the value $\sigma_y$. But this would require the average true stress to exceed the value actually developable by the material, as indicated by the increased tangent modulus $E'_t$. Therefore *an ideally plastic material will not neck down.* This statement applies, of course, to ideal specimens having no initial necks, but we shall see later that the effects of small eccentricities tend to be offset by the stabilizing influence of the neck.

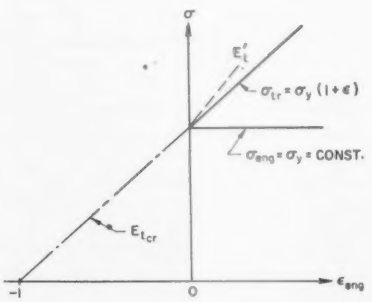
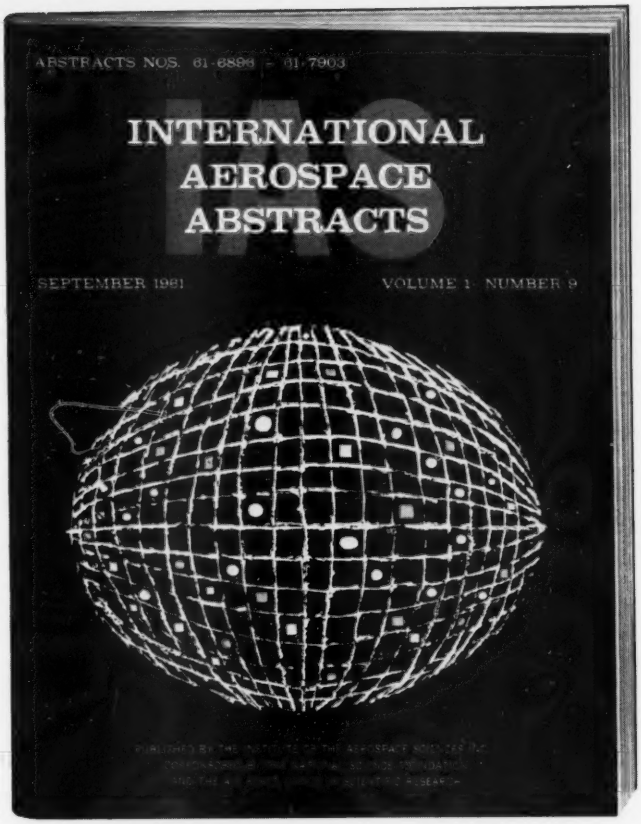



Fig. 7. Stress-strain diagram for an ideally plastic material, plotted against engineering strain.

## Formation of the Neck

We now consider a material for which the flow stress-strain diagram—i.e., the one that would have been obtained if the material had *not* necked down—falls below the curve for constant load. In such a case, it is possible for a neck to develop as the strain is increased beyond that corresponding to the maximum load. The shape of the neck and the rate at which it forms are evidently governed by certain laws and it should be possible to predict the behavior after necking begins. This appears at first sight to be a very complicated phenomenon, similar to the prediction of




# Are you really keeping abreast of aerospace developments?

Today's aerospace technology moves *fast*. Every forward-looking engineer and scientist *must* know the results of all aerospace research related to his own work *wherever accomplished*.

INTERNATIONAL AEROSPACE ABSTRACTS is ideally suited to help you with this task—made enormous by an avalanche of publications.

INTERNATIONAL AEROSPACE ABSTRACTS saves you time. Each monthly issue gives you about a thousand abstracts of the latest reports, articles, meeting papers, and books—selected because they *are* important to aerospace technology. You can immediately put your finger on the work being done in your field. COVERAGE IS WORLD-WIDE.

INTERNATIONAL AEROSPACE ABSTRACTS is cosponsored by the National Science Foundation and the Air Force Office of Scientific Research. For detailed information on this indispensable R & D tool, write to the address below.

## Enter Your Subscription Now!

INTERNATIONAL AEROSPACE ABSTRACTS
2 East 64th Street, New York 21, N. Y.

Please enter ____ subscription(s) for the year 1962 at the following rates:

- ☐ Individual IAS Member Rate – $20/yr
- ☐ Corporate IAS Member Rate – $40/yr
- ☐ Nonmember Rate – $60/yr
  - ☐ Payment is enclosed.
  - ☐ Please send bill.

Name_____ Title_____

Company_____

Address_____

City_____ Zone____ State_____

**INSTITUTE OF THE AEROSPACE SCIENCES, INC.**

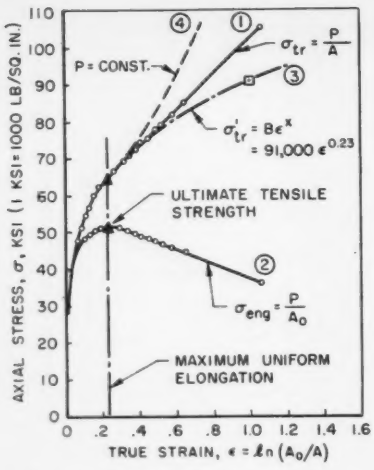

AXIAL STRESS, σ, KSI (1 KSI = 1000 LB/SQ. IN.)
TRUE STRAIN, ε = ℓn (A₀/A)
P = CONST.
σtr = P/A
σ'tr = Bε^K = 91,000 ε^0.23
ULTIMATE TENSILE STRENGTH
σeng = P/A₀
MAXIMUM UNIFORM ELONGATION

Fig. 8. Stress-strain diagrams for annealed mild steel bar. (Test data from Fig. 11 of Ref. 4)

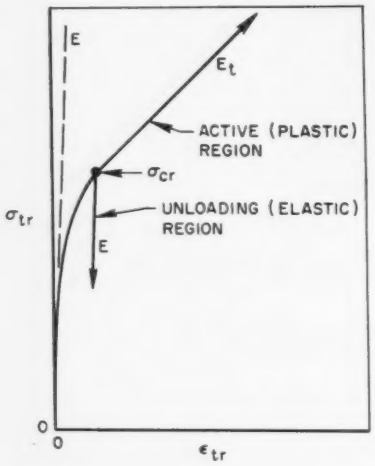



Fig. 9. Stress-strain diagrams for plastic and elastic regions.

the behavior of an inelastic column after it has begun to buckle. However, a theory of neck formation can be derived for a simplified model, as follows.

Our first clue is found in the work of McGregor[3-6] who proved experimentally that the stress-strain relationship at the root of the neck is always linear (or at least very nearly so) when the average true stress is plotted against true strain, as in Fig. 8. Apparently this relationship has never been explained. We shall advance the hypothesis that *this straight line represents the basic law of necking.*

One way to examine this hypothesis is to treat the phenomenon on the energy level. On the true-stress true-strain diagram an element of area represents energy per unit volume. We know also that when necking occurs the load decreases. This causes a decrease in true stress in the nonnecking (inactive) portion of the specimen, thereby releasing elastic energy in that portion. From the second law of thermodynamics we can deduce that the neck will form in such a manner that the greatest possible amount of elastic energy (in the specimen and testing machine) will be converted into heat.

From Hooke's law, the release of unit elastic energy in the unnecked portions of the specimen is represented by a linear unloading line on the stress-strain diagram, as shown in Fig. 9, where elastic strains have been included (exaggerated). *If the relative volumes of the necking and nonnecking regions remained constant,* it would follow from the above statements that the curve for the necking region would have to be linear. This would explain the experimental results.

However, we know that the volume of the active (plastic) material in the neck does not remain constant, but decreases during the necking process. We can also conclude that for a "perfect" specimen (with no initial necks) the profile radius, $R$, must start at infinity at the critical point, becoming progressively smaller. Therefore, the volume of active material starts out as that of the entire specimen* and progressively decreases. One would therefore expect the slope of the straight line to decrease as this goes on, since more elastic energy is being released and this requires greater plastic strains (for the same stress level).

An examination of test data for many materials[3-6] shows that the experimental straight line (for $\sigma_{avg}$) almost always has a somewhat lower slope than that represented by the tangent to the curve at maximum load. This would seem to indicate that the theoretical stress-

* Specimen refers here to the portion having an initial constant diameter.

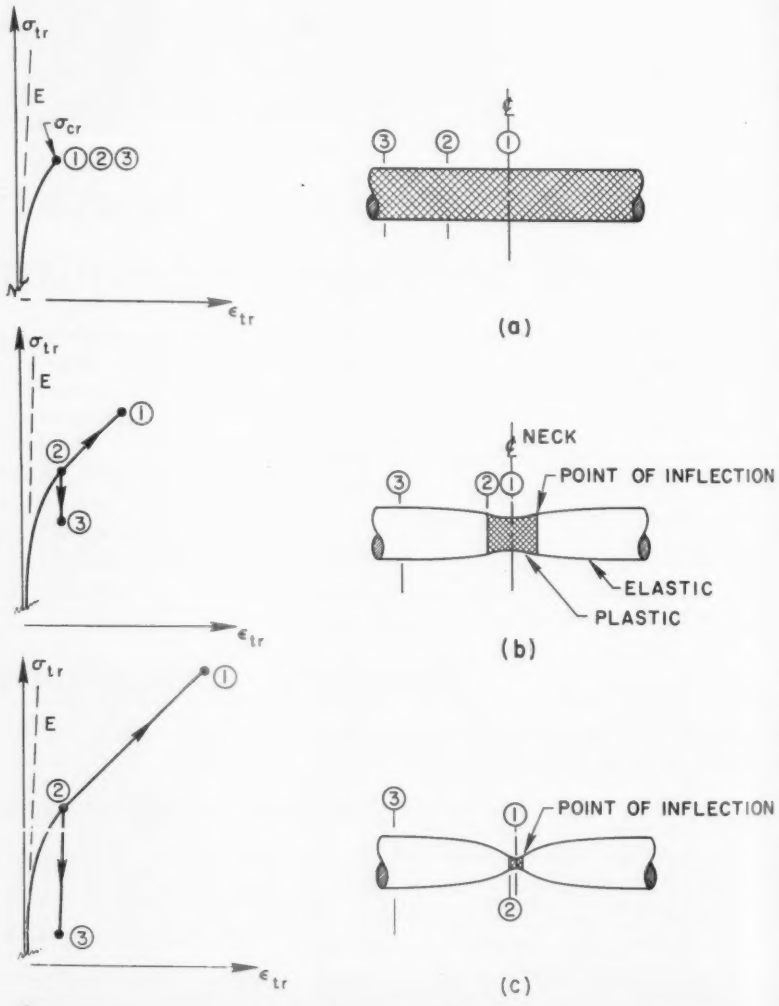



Fig. 10. Various stages of necking.

strain curve for the neck is not actually straight, but is asymptotic to a straight line. The curvature at the lower end is too small to be detected from test data, but the reduction in slope that is observed can possibly be explained in this manner.

Up to this point we have been discussing only the stress-strain relationship at the root of the neck. If the foregoing theory is correct, the basic law should apply at all cross sections in the active zone. This means that stress-strain measurements at all cross sections within the active zone should also fall on the straight line. McGregor's tests showed that this is true.

It is now possible to visualize the phenomenon of neck development by the following conceptual model. First we must assume a "flow" stress-strain diagram, since we cannot obtain this from a tension test. Next we draw a straight line representing the critical slope, at maximum load. (We shall, in this model, neglect the fact that the actual necking diagram has a somewhat lower slope.) This represents the average stress ($\sigma_{avg}$) at any cross section in the active region of the neck. We can obtain Bridgman's constraint factor by dividing one stress by the other—i.e.,

$$k = \sigma_{avg}/\sigma_{flow}$$

Then, using Eq. (15) or Fig. 5, the value of $a/R$ can be determined for any value of $k$. As the beginning of necking, $\sigma_{avg} = \sigma_{flow}$ and $k = 1.0$. Therefore $R = \infty$ and the specimen contour is straight. Assume now an increment of strain $\Delta\epsilon$, beyond the critical point. Then $\sigma_{avg}$ becomes greater than $\sigma_{flow}$. This gives a value of $k$ greater than unity and a finite value of $R$ is obtained. The depth of the neck can be found by noting that $\Delta\epsilon = ln\ (A_1/A)$, where $A_1$ = actual area at critical point. Then $\Delta\epsilon = 2\ ln\ (a_1/a)$, where $a_1$ = radius of cross section at critical point. From this,

$$a = a_1 e^{-(\Delta\epsilon/2)}$$

The value of $a$ locates the depth of the osculating circle.

An approximate graphical development of the neck contour was carried out by following this procedure through successive increments of strain in a step-by-step procedure. Even without making corrections for constant volume, the resulting neck contour was similar in shape to that obtained in a test. An important fact revealed by such a procedure is that there is a *point of inflection* which moves inward from each end as the neck develops. This marks the boundary between the active (loading) and inactive (unloading) zones, as shown in Fig. 10. The contour of the inactive portion of the neck is represented by the locus of these points of inflection as they move inward from the ends. Fig. 10 also indicates how the point of inflection moves toward the midpoint of the specimen, causing a decrease in active (plastic) volume. The stress-strain diagrams show, schematically, the correlation with points on the specimen.

The contour of the active portion is, of course, not circular. As we move away from the root of the neck, the average stress decreases with increasing diameter and the factor $k$ becomes less. Therefore, $R$ becomes greater. This explains the approximately hyperbolic shape observed in the active region. Moellendorff (Ref. 1, p. 82) found that the shape of the inactive portion of the neck is about the same for all materials.

If actual failure occurs before the neck is fully developed—i.e., before the root area is reduced virtually to a point—the broken specimen will retain a hyperbolic shape in the active region. The extent to which the neck develops is obviously controlled by the (cohesive) strength of the material in the interior of the root, where the true stress is a maximum.

Moellendorff also developed an empirical expression for the neck shape. This expression could perhaps be derived by using a simplified model and performing the above manipulations mathematically. However, we are usually not particularly interested in the shape of the neck after it has become well-developed, but are more interested in the transition region in the neighborhood of maximum load (the same statement can be made about column theory). We must also examine the effects of initial eccentricities, since no actual specimen can be perfect, as assumed in the foregoing analysis.

## Applications and Refinements of the Theory

One of the serious problems encountered in improving the tensile strength of materials is the reduction in uniform elongation that almost always occurs when the ultimate tensile strength is increased (by alloying, heat-treatment, cold-working, etc.). Fig. 11 shows the history of some aluminum alloys (from Ref. 7). The progressive reduction in uniform elongation is quite evident.

An insight into this phenomenon can be obtained by using an empirical equation for the relationship between true (plastic) strain and true stress. If the power function is used, we have

$$\epsilon = (\sigma/B)^n \qquad (16)$$

where $B$ and $n$ are empirical constants.

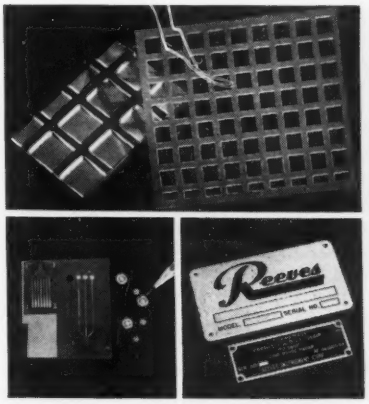
This is usually written in the form

$$\sigma = B\epsilon^x \qquad (17)$$


NEW KODAK

METAL-ETCH RESIST

opens new chemical-milling applications




Speeds up, simplifies *deep etch* weight reduction and parts manufacture. Reproduces fine-line detail as in plating, dial and name-plate making. This new photographic process ends time-consuming handwork, results in high accuracy. Kodak Metal-Etch *Resist* withstands acids, alkalies, electrolytic fluids . . . adheres well to aluminum, titanium, magnesium, stainless and other alloy steels. High stability and strict uniformity simplify volume production. Send today for a detailed 16-page brochure that gives all the facts.

Text for this advertisement was set photographically.

*No statement or suggestion is to be considered a recommendation or inducement of any use, manufacture or sale that may infringe on any patents now or hereafter in existence.*

*Graphic Reproduction Sales Division*
**EASTMAN KODAK COMPANY**
Rochester 4, N. Y.

**Please send me a copy of the booklet, "Etching, Chemical Milling and Plating with Kodak Metal-Etch Resist" (P-36).**

Name _____
Company _____
Street _____
City _____
Zone ____ State _____

12-251

Kodak
TRADE MARK

where $x = 1/n$ = "strain-hardening exponent."*

Many authors have shown that a good fit is obtained by using this power function. As shown by Nadai,[1] the use of Eq. (17) together with Eq. (9) gives

$$d\sigma_{tr}/d\epsilon_{tr} = B\,x\,e^{x-1} = \sigma_{cr} = B\epsilon_{cr}^{x}$$

from which $\epsilon_{cr} = x$ (18)

This simple result enables us immediately to predict the elongation corresponding to ultimate tensile stress by plotting the true-stress true-strain diagram on log-log paper.

Smaller values of $x$ (or larger values of $n$) correspond to sharper "knees" in the stress-strain diagram. It is evident that the reduced elongation of high-strength ductile materials is a result of the *shape* of the stress-strain diagram.

Improvement in ultimate tensile stress (for a ductile material) is achieved largely by making slip more difficult so that the stress may be raised to higher values before appreciable slip occurs. When it does occur, it increases more rapidly with increasing stress, thereby accounting for the sharper "knee." The unfortunate thing about this is that many high-strength materials have rather high potential uniform elongation (as indicated by the reduction of area at the root of the neck), but this cannot be developed over the entire length of the member because of the early occurrence of necking.

It is easy to see what must be done to achieve better utilization of the potential elongation of a material. If it is desired to raise the ultimate tensile stress without decreasing uniform elongation, it is necessary that the true-stress true-strain diagram reach the desired value of $\sigma_{cr}$ (in Fig. 3) without crossing (or becoming tangent to) the constant load line through $\sigma_{cr}$. For example, Fig. 12 shows two different ways to raise the ultimate tensile stress from 51,700 psi (Curve 1) to 70,000 psi. If the stress-strain diagram follows Curve 2 the original uniform elongation of 23 percent is retained. But if it were to follow Curve 3 the uniform elongation would be reduced to about 8 percent. This shows that a relatively small change in the shape of the diagram can have large effects on uniform elongation. In the study of dislocations, alloying, heat-treatment, etc., it would be desirable to keep these facts in mind.

Another interesting possibility is the changing of the shape of the true stress-strain diagram by a change of strain rate. For a rapidly increasing strain rate the true stress-strain diagram might be made to curve upward, thereby preventing necking, or delaying it until much greater uniform elongation is developed. This may be one of the important factors in "explosive forming."

To demonstrate the fact that the nominal ultimate tensile strength is not a true material property two specimens were made, one of which had integrally machined fins, as shown in Fig. 13. (The material was "half-hard" brass.) Both specimens had the same minimum diameter (approximately 0.500 in.). The plain specimen developed an ultimate tensile stress of about 50,000 psi; the finned specimen developed 70,000 psi (maximum load divided by original cross-sectional area). The 40-percent increase in apparent strength is of course caused by the fact that the fins prevented the cross section from decreasing freely.

Since no specimen can be perfect, we must assume that some form of "eccentricity" will always exist. For the tension specimen the simplest form of eccentricity is a shallow concentric neck. At the root of such a neck the average true stress will be greater than at other sections. One would therefore expect the neck to contract more rapidly than the rest of the specimen, since the rate of strain (with increasing stress) will apparently be greater in the necked region. But careful measurements by Reiner,[8] Lubahn,[9] and others have shown that shallow necks which form well below the maximum load tend to "wash out." In effect, they travel over the length of the specimen, the overall result being an apparent uniform reduction in diameter.

This can be explained by the stabilizing effect of the radial stresses. As previously shown, a shallow neck causes an apparent increase of stiffness against plastic deformation (see $E'_t$, Fig. 6). On the other hand, the profile of the specimen on either side of a neck has a convex shape, which produces radial *compressive* stresses. These tend to increase the internal shear stresses and thereby reduce the resistance to plastic deformation ($E'_t$ would be less than that for the unnecked material). The combination of these effects is evidently sufficient to cause the traveling wave phenomenon usually observed in tests.

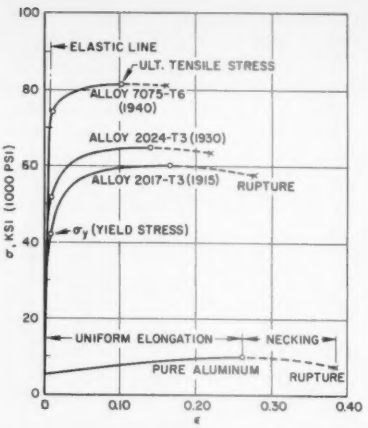



Fig. 11. Effects of alloying and heat-treating on aluminum (typical material).

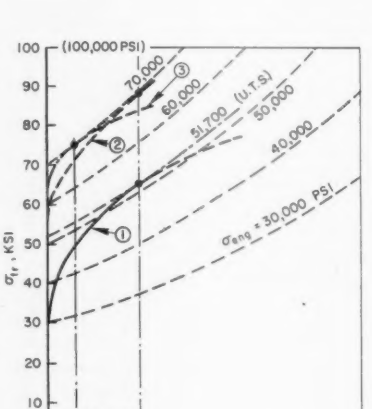



Fig. 12. Different ways of raising the ultimate tensile stress.

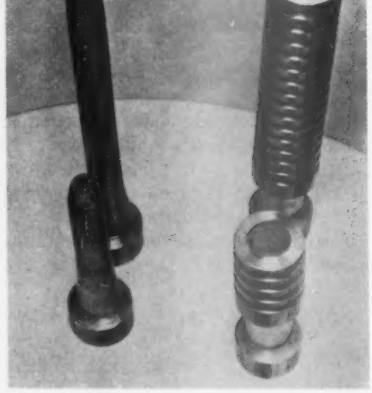


Fig. 13. Comparison of standard and finned tensile specimens.

## Recommendations for Research

One of the objects of this paper has been to reveal areas toward which future research and development work should be directed. Some of these are itemized below.

### *Stress Distribution in Necked Region*

The constraint factor used in the theory [Eq. (15)] is based on several simplifying assumptions. As Bridgman himself implied, it does not include the complete effects of conditions adjacent to the root of the neck. For very shal-

* The author prefers Eq. (16) because it permits the plastic strain to be added to the elastic strain in a logical manner.

low localized necks the assumption that the axial strain is uniform across the neck may be questionable. For one thing, it does not take into account the elastic stress-concentration effect that existed prior to plastic straining.

### Comparison With Inelastic Column Theory

The tensile instability phenomenon has much in common with the phenomenon of buckling under compressive loads. In previous papers[10, 11] the author showed that the lower and upper bounds for the maximum compressive load of an inelastic column are given by the Engesser (tangent-modulus) and von Kármán (double-modulus) theories. The exact computation of the maximum column load has since been achieved by various authors, for both columns and plates.

In tension, the lower and upper bounds for the necking curve are, respectively, the "flow" diagram—i.e., the one that would have been obtained if necking had not occurred—and the curve representing constant load, as indicated in Fig. 8. (The reduction of elastic energy would be zero in both cases.) Furthermore, it appears that the stress-strain diagram for the "active" necking region is asymptotic to a straight line which lies between these two bounds. The critical slope, $E_{t_{cr}}$, is analogous to the Engesser tangent modulus. It would appear that a second value of $E_t$, analogous to the Kármán double modulus, might be established by including the effects of radial stresses. To do this would require a conceptual model involving the same type of paradox as that represented by the Kármán model and described in Ref. 10. However, the author has been unable, so far, to come up with a simple mathematical model of this type.

The mathematical analysis of the transition range immediately following the attainment of maximum load appears to be rather difficult, as in column theory. Nevertheless, this is a subject of considerable interest for materials with relatively flat-topped engineering stress-strain diagrams.

### Time Effects

The helpful effect of a continuously increasing rate of strain has been mentioned in connection with explosive forming. Another interesting phenomenon is that of creep under constant load. In such a test the engineering stress-strain diagram is, of necessity, flat-topped. Unless radial stresses are considered it might therefore be concluded that necking would begin immediately, if at all. Hoff[12] used such an assumption in developing a theory of necking for creep (a small initial eccentricity was used as a starting point). He noted, however, that radial stresses might change the results, particularly for round specimens. In actual creep tests, large plastic strains can be developed before any appreciable necking can be observed. This indicates that the stabilizing influence of radial stresses is preventing the continued deepening of any small local eccentricities (necks).

Nadai (Ref. 1, p. 85) refers to papers by Ilyushin and Ishlinsky, who developed a theory for the necking of a viscous material. Their results appear to be in general agreement with the above line of reasoning. Strain rate was found to be the controlling parameter.

### Size Effects

A more detailed mathematical theory of necking, when finally developed, should reveal certain geometric parameters which tend to affect the sensitivity to initial eccentricities, behavior in the transition region, etc. The most important parameter involved is no doubt the length-diameter ratio. It has long been recognized that this parameter has an effect in tensile tests. The diameter itself may also play a direct role. It would be interesting to investigate what happens when the diameter becomes very small, as in fine filaments (whiskers).

### Combined Loading

The extension of the classical (load-maximizing) theory to conditions of combined loading has been the subject of many papers and is of special interest in the design of efficient pressure vessels. A better understanding of tensile instability for simple tension will, it is hoped, lead to improved theories and methods for predicting the bursting strength of pressure vessels.

The wide plate in tension also falls in this category, because necking will take place along a diagonal line, involving combined stresses. Bijlaard has very neatly explained this (see Nadai's discussion, Ref. 1, p. 322). It would be useful to extend the foregoing analysis to include such specimens.

### Metallurgical Aspects

It has been shown that the uniform elongation is very sensitive to the *shape* of the true stress-strain diagram. It is therefore important to apply our knowledge of solid-state physics, dislocation theory, etc., to control this shape. In this connection it should be noted that it is difficult, if not impossible, to determine the flow diagram, in the necking region, by tension tests. Methods of circumventing this difficulty should be developed. The compression test, if properly made, may supply useful information.

## References


[1] Nadai, A., *Theory of Flow and Fracture of Solids*, McGraw-Hill Book Co., Inc., New York, 1950.

[2] Bridgman, P. W., *Studies in Large Plastic Flow and Fracture*, pp. 9–32; McGraw-Hill Book Co., Inc., New York, 1952.

[3] MacGregor, C. W., *Differential Area Relations in the Plastic State for Uniaxial Stress*, pp. 134–146; Stephen Timoshenko 60th Anniversary Volume, The Macmillan Co., New York, 1939.

[4] MacGregor, C. W., "The Tension Test," *Symposium on Significance of the Tension Test of Metals in Relation to Design*, Proc. of ASTM, Vol. 40, pp. 508–534, 1940.

[5] MacGregor, C. W., *Rapid Tension Tests Using the Two-Load Method*, Tech. Publ. No. 1393, AIME, Metals Technology, Dec. 1941.

[6] MacGregor, C. W., *True Stress-Strain Relations at High Temperatures by the Two-Load Method*, Tech. Publ. No. 1507, AIME, Metals Technology, Sept. 1942.

[7] Shanley, F. R., *Strength of Materials*, p. 160; McGraw-Hill Book Co., Inc., New York, 1957.

[8] Reiner, M., *Deformation and Flow*, pp. 195–200; H. K. Lewis and Co., Ltd., London, 1949.

[9] Lubahn, J. D., *The Necking of Tensile-Test Specimens*, Trans. ASME, pp. 277–279, May 1946.

[10] Shanley, F. R., *The Column Paradox*, Journal of the Aeronautical Sciences, Vol. 13, No. 12, p. 678, Dec. 1946.

[11] Shanley, F. R., *Inelastic Column Theory*, Journal of the Aeronautical Sciences, Vol. 14, No. 5, pp. 261–267, May 1947.

[12] Hoff, N. J., *The Necking and the Rupture of Rods Subjected to Constant Tensile Loads*, J. Appl. Mech., Vol. 20, No. 1, pp. 105–108, March 1953.



**Change of Address**

Since the Post Office Department ordinarily does not send magazines to forwarding addresses, it is important that the Institute be notified of changes in address 30 days in advance of publishing date to ensure receipt of every issue of the *Journal of the Aerospace Sciences* and *Aerospace Engineering*.

Notices should be printed legibly and sent directly to the Circulation Department, Institute of the Aerospace Sciences, Inc., 2 East 64th Street, New York 21, N.Y.

## Rapid Sea-Wide Supply

(Continued from page 19)

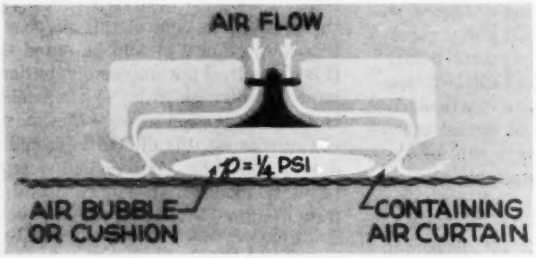



Fig. 3. Peripheral jet.

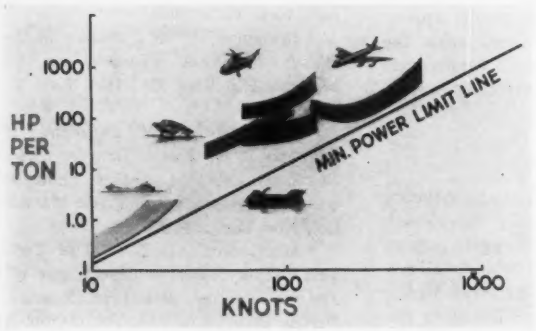



Fig. 4. Transport comparison.

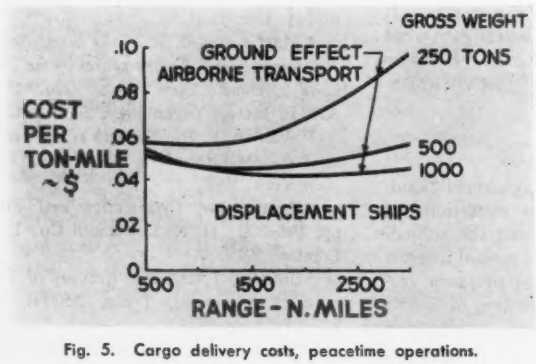



Fig. 5. Cargo delivery costs, peacetime operations.




Fig. 6. Cargo delivery costs, wartime operations.

toward a low, functional profile with essentially straight-line elements which permit the structure, although aircraft-type, to be simple and low in cost.

The basic operating principle is indicated in Fig. 3. Note the very low planform-loading pressure, or bearing pressure, at which these vehicles operate. A typical value would be 0.25 psi, or 36 lbs per sq ft. An entrapped low-friction bubble of air supports the vehicle, in a manner similar to that of the air bearing used in some gyroscopes. Then, by the application of forward thrust, the vehicle slides along, not requiring a great deal of power for speeds up to 100 knots. Power requirements remain nominally low until aerodynamic drag becomes appreciable at the higher speeds.

The operational altitudes are very low, as I previously indicated, and the closer these vehicles are operated to the water, or ground, the less the power and fuel required and the higher their efficiency becomes. Because of this relationship between operating efficiency and water clearance, economy will vary with sea conditions. Analysis of the wave-height distribution in the oceans of the world indicates that a GEM of 500-ton gross weight would be able to operate 50 percent of the time at a 3-ft, or less, average altitude; closer when the sea is calm, higher and probably slower when it is rough. In the following economic analysis, the operational altitude of 3 ft was utilized.

Fig. 4 indicates the relative place of the GEM as a transportation vehicle. It is not as economical as a displacement ship for carrying slow nonspoilage cargo, nor as fast as aircraft; but it appears to have some of the desirable characteristics of both.

A GEM will be able to travel at from 3 to 4 times the speed of any of our displacement ships, in a speed range that is occupied by neither ships nor aircraft. When plotted as shown here, in the parameter of installed horsepower per ton, the GEM lies in a direct line with the more efficiently designed ships and large cargo aircraft. It is somewhat akin to the helicopter, also shown on the chart, but is designed to operate with greatly increased efficiency within the ground effect phenomena. The GEM requires less than one half the installed horsepower per pound of the helicopter, and is not cargo-volume limited as is the latter. Hydrofoil ships most certainly hold promise as a competitor; however, unlike the GEM, they appear to have technological limitations in the larger sizes. Other problems, such as high-sea-state capability and the effects of damage from objects in the water when foil-borne, are also unknowns. In the polar, ice-infested areas, hydrofoil ships are impractical.

Figs. 5 and 6 illustrate the expected cost per ton-mile of the GEM relative to displacement ships. Fig. 5 shows that, for peacetime nonconvoyed operations, the conventional ship offers the best economy of operation. As the GEM transport increases in

size from 250 to 500 to 1,000 tons, the cost per ton-mile decreases and the minimum occurs at longer ranges. The displacement-ship shaded area encompasses the various types of cargo ships and the upper, least efficient, boundary is the LST.

Fig. 6 illustrates the GEM's distinctly competitive position when the cost of protection against submarines is added. The increased costs for operating tankers or ammunition supply ships with escorts under wartime conditions are estimates which include the cost of operation of the escorts, a factor for escort losses, a factor for cargo and ship losses, and a factor for weapons expended in false and real submarine contacts. The data used in these cost factors were obtained from World War II naval data and projected by the Navy-formed White Oaks committee to the present-day situation.

The ability of the GEM to fly above the surface of the ocean entirely changes the submarine warfare aspects for this vehicle. With its speed advantage and lack of sound transmitted to the water, the GEM would *not* be vulnerable to the submarine. The importance of this point cannot be overemphasized. Accordingly, GEM operating costs were not increased by these antisubmarine warfare expenses and losses.

The value of transit of heavy cargo, either shore-to-shore or shore-to-ship at fairly high speeds, such as 100 knots, is difficult to assess. There are many factors related to the importance of a rapid transit system, such as (1) lives saved because ammunition, fuel, or some other cargo is available; (2) savings in the logistics pipeline; and (3) additional firepower which could be brought to bear because of expedited supply in vehicles not vulnerable to the submarine.

The promise that these vehicles hold for the future cannot be overlooked; however, the state of development is such that it is not clear that the foregoing potentials can be fully realized. There are unknowns to be uncovered and known problems to be solved. Some typical problems are: (1) underside shape, (2) rough-water sea-keeping capability, (3) spray and corrosion, (4) power-plant development, and (5) stability and control.

The optimum underside shape, to gain lift and yet handle rough-water wave-impact loading and vehicle response, is far from determined. The rough-water sea-keeping capability is undoubtedly the foremost problem and may require that very large experimental models be built. And, of course, there is the spray and corrosion problem and the desirability of developing larger engines, such as the regenerative type which combines aircraft lightweight technology with the economy of operations associated with large, stationary, power plants. Other problems, such as static and dynamic stability and control, will also require significant efforts.

If we assume, however, that by proper emphasis, vehicles *can* be developed to provide a rapid sea-wide supply system, some imaginative pictures of the future can result.

Large ocean-going GEM's of 500- or 1,000-ton capacities can sweep out from continental and overseas naval bases and, traveling in excess of 100 knots, deliver supplies to ships in any operational waters of the world—in less than one day. Also, for refer-

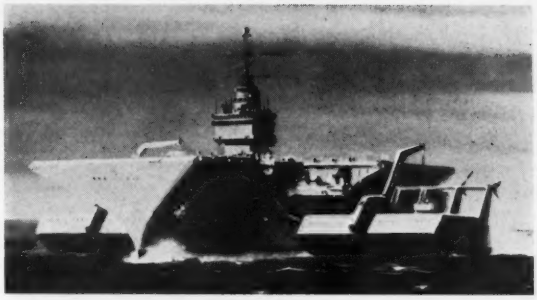


Fig. 7. Use of GEM as tanker transferring fuel to aircraft carrier at full cruise speed is shown.

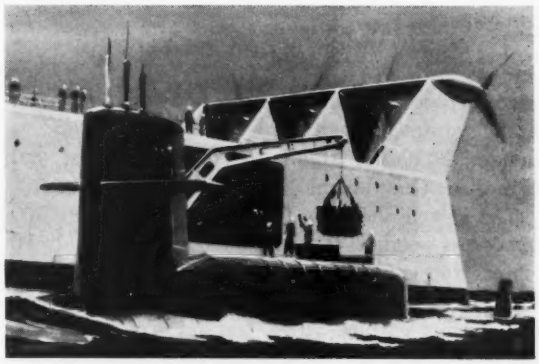


Fig. 8. GEM shown as submarine tender.

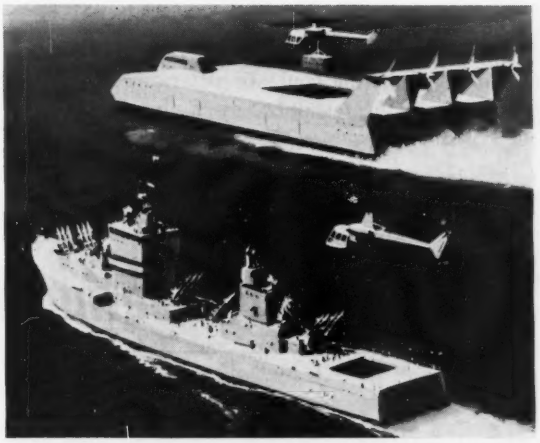


Fig. 9. Cargo transfer of fresh supplies from GEM to nuclear ship is carried out at cruising speeds.

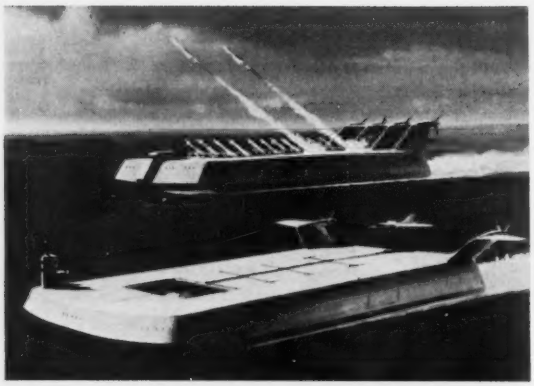


Fig. 10. Possible uses of GEM's for naval task forces include aircraft carrier, guided missile launcher, and destroyers or submarine killers.

ence purposes, typical en route times would be: San Francisco to Honolulu, 20 hours; New York to London, 30 hours; Manila to Tokyo, 16 hours; and Norfolk to Guantánamo, less than 10 hours.

The vehicle shown in Fig. 7 is approximately 500 tons gross weight. It would have a crew of 10 to 20 officers and enlisted men, and might be 100 ft wide and 250 ft long. It is illustrated transferring fuel to the aircraft carrier. Fuel transfer would be conventional; however, there would be a significant difference. It would not be necessary for the carrier to slow down to the tanker's speed; instead, it could continue at normal cruising speed to minimize vulnerability during the resupply operation.

One of the major problems of Polaris submarine resupply in the future may be security. If the position of a submarine could be determined by being tracked from the resupply vessel, this could make our Polaris force vulnerable. The absence of significant sonar signals for tracking and its relatively high speed would enable the GEM to assure the submarine's safety during a rendezvous (Fig. 8).

In Fig. 9 we see a nuclear cruiser or frigate being resupplied at cruising speed. A crane helicopter, or VTOL, might operate from the large, flat, upper surface of the GEM to accomplish the cargo transfer, or conventional techniques might also be used.

And, of course, eventually such craft with their potential speed and invulnerability to submarines would not be limited to logistic applications. They could become the central elements of our task forces of tomorrow, such as aircraft carriers, guided missile cruisers, and destroyers or submarine killers.

An interesting thought occurred to me when I first saw Fig. 10. With a GEM being used as an aircraft carrier, an aircraft would have no lengthy landing or take-off roll, since both the carrier and the aircraft would fly at 100 to 150 knots. But we would have to worry about how to hold the aircraft down until we could get it below decks.

It is clear that, if this form of transportation can be successfully attained, it offers great potential to the Navy. It is also apparent that, today, we cannot predict with certainty the ultimate performance and behavior of these craft. We have been careful to point out the problems and unknowns that exist and can only recommend that the Navy consider carefully the development of GEM research vehicles. Craft should be built in sufficient size to provide answers to such fundamental questions as sea-keeping capability, speed, and economy of operation.

The next 50 years of naval aviation will undoubtedly see many changes, and the COD and the GEM rapid resupply systems which I have discussed could very well play crucial roles in achieving faster replenishment of ships at sea during this period.

✦ ✦ ✦


# CAI-IAS Joint Meeting Papers

**Ottawa, October 23–24, 1961**

**61-214** The Use of Helicopter Support in Polar Operations—W. C. E. Loftus and J. P. Croal

**61-215** Transpolar Jet Navigation—E. S. Pedersen

**61-216** Naval Aviation in Antarctica—William H. Munson

**61-217** Aircraft Landings on Ice—T. G. Dunkin

**61-218** Flight Testing the C-130BL "Hercules" in the Antarctic—P. D. Gillich and H. B. Dees

**61-219** Some Aspects of Cold Weather Testing and Operation of Aircraft—K. Weinstein

**61-220** Commercial Experience in Cold Weather Operation—P. A. Hartline

**IAS Member Price—$0.50 each** **Nonmember Price—$1.00 each**

***Order by number from:*** **Special Publications Dept., IAS, 2 E. 64th St., New York 21, N.Y.**

# Curtiss A-1 Replica

(Continued from page 21)

Completed parts were delivered to the North Island Naval Air Station and the replica slowly came to life, with the Navy Overhaul and Repair Department—under Captain Paul Gill's command—assisting with final assembly. Ray Fife, one of their chief mechanics, supervised the operation under the guiding hand of Cdr. Jim Irvine, as the Project Officer. No aircraft was ever built with more loving care.

Lou Robbins, Navy power-plant specialist, rebuilt and tuned the OX-5 engine until it reached rated bhp in a throaty roar. It took real fortitude to keep from wearing the engine out on the test stand!

Because of the number of donors and the thousands of donated man-hours, giving adequate credit and recognition is about impossible. However, to carry the spirit of the A-1 project on into the future, the IAS/Navy A-1 Club was formed. A complete list of its members is included in Table 1. Because of all the unstinted effort devoted to this project, we can justly say that the Curtiss A-1 is A-OK in every way!

### Model Tests

While construction was progressing, so also was an 8 by 10 wind tunnel test of an austere 1 to 5.5 scale model by the Aerodynamics Laboratory, David W. Taylor Model Basin[2] (Figs. 4 and 5). This model was built of aluminum plate and mahogany, verified on a plane table for accuracy of wing and control settings. The rudder, horizontal stabilizer, and bow plane could be given any desired setting by fastening devices. The elevators and ailerons had adjustable settings through the normal control range of the full-scale aircraft.

The data of most interest are shown in Fig. 6 (basic performance), Fig. 7 (force vectors at 62 mph), and Fig. 8 (lift and drag versus angle of attack). Parameters checked were lift, drag and side forces, and pitching, yawing, and rolling moments at roughly 60 mph and various settings to the wind.

Analysis of this and other related reports prepared by IAS engineers indicated the following pertinent predicted flight characteristics.

(1) Low static-stability levels.

(2) Poor force balance between lateral (quite high) and directional (relatively low) control forces.

(3) Lifting ailerons would produce high adverse yaw in turns.

(4) The aircraft would exhibit a "jump characteristic" upon leaving the water because of the flat hull bottom.

(5) Skid fins installed between the wings and the upper half of the inboard interplane struts would reduce $C_{N\beta}$ which was already deficient.

Fig. 2. A-1 on beach at San Diego, early 1912.

(6) High basic drag would result in high power-off sink rates.

(7) Lack of wing dihedral would cause spiral instability.

### Flight Tests

Expectantly, on July 3rd, 1961, initial launching took place in San Diego Bay. Ballasting was checked at 31 percent M.A.C. With Ray Fife on the bow of the float, the airplane left its cradle and was afloat. What a soul-satisfying sight!

But all was not well. Fife couldn't move to the pilot's seat without the tail's getting dunked. The A-1 was beached. Verville then established that the original A-1 had essentially this same characteristic. With power on, the high thrust line kept the nose down. Apparently it took a nimble pilot to get out of the seat and on the bow when the engine failed on the water.

Since a landing-gear rig had been built in case a back-up should be required, considerable discussion took place as to whether the A-1 should fly off wheels as a landplane instead of as a seaplane.

The major objective of this program was to re-enact the original seaplane flights, therefore most of the group were undaunted by this turn of events. After all, this is par for the course in flight testing! To correct this center-of-buoyancy discrepancy, a 3-cu-ft balsa block was attached to the rear of the float. This was tailored by sawing chunks off until the replica floated at the proper trim angle statically. The balsa block was replaced by an aluminum tank of equivalent volume, looking very much like a bustle on the rear of the float.[3] The shape was designed to prevent high water-landing loads and hydrodynamic directional instability due to vortices shedding off the trailing edge.

JULY 9TH—The first taxi operation was completed at maximum gross weight with the engine secured. The purpose: aircraft and boat crew coordination drill. The A-1 was secured between two boats, one with a bow line, the other a stern line attached to the float. Signaling procedures and line-handling techniques were evaluated and modified as required.

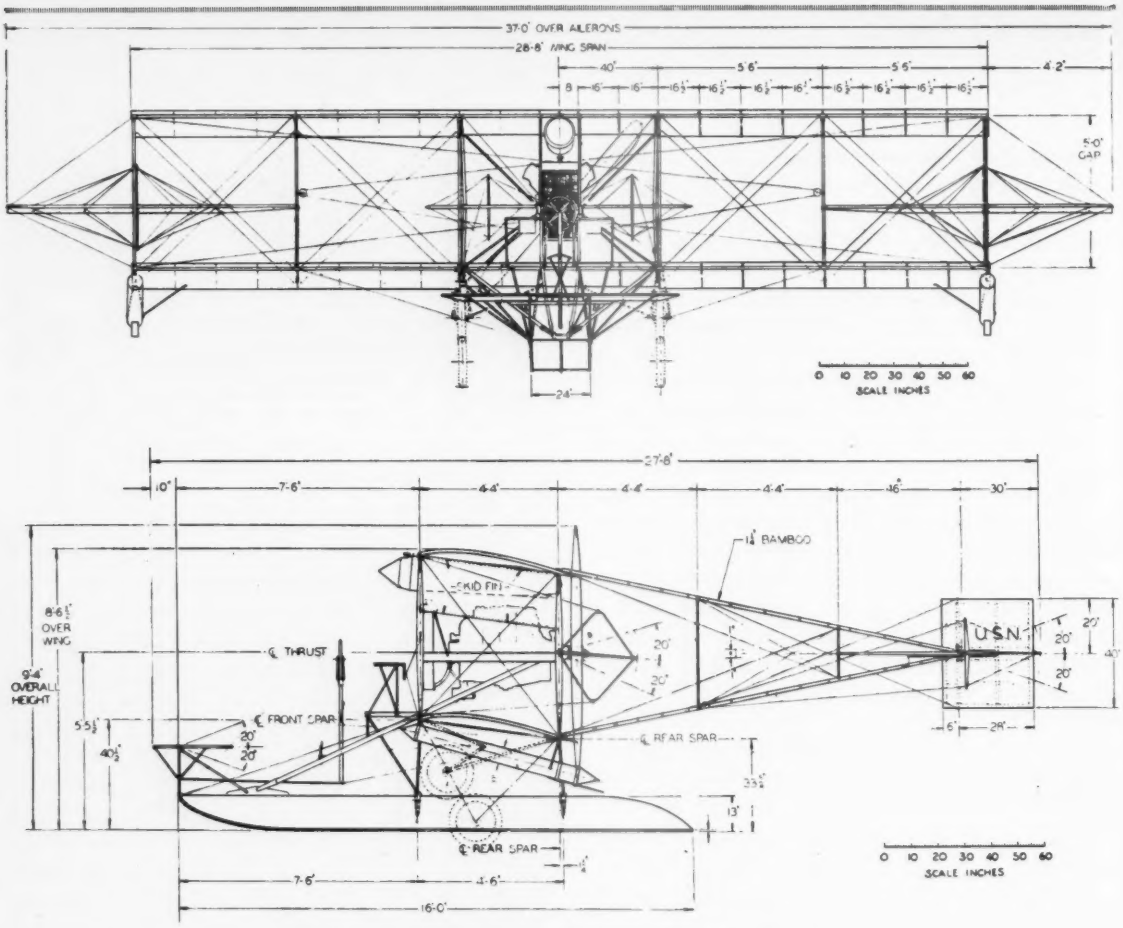



**Fig. 3. Blueprints for the A-1 replica. [See also facing page.]**

**Aircraft Characteristics**

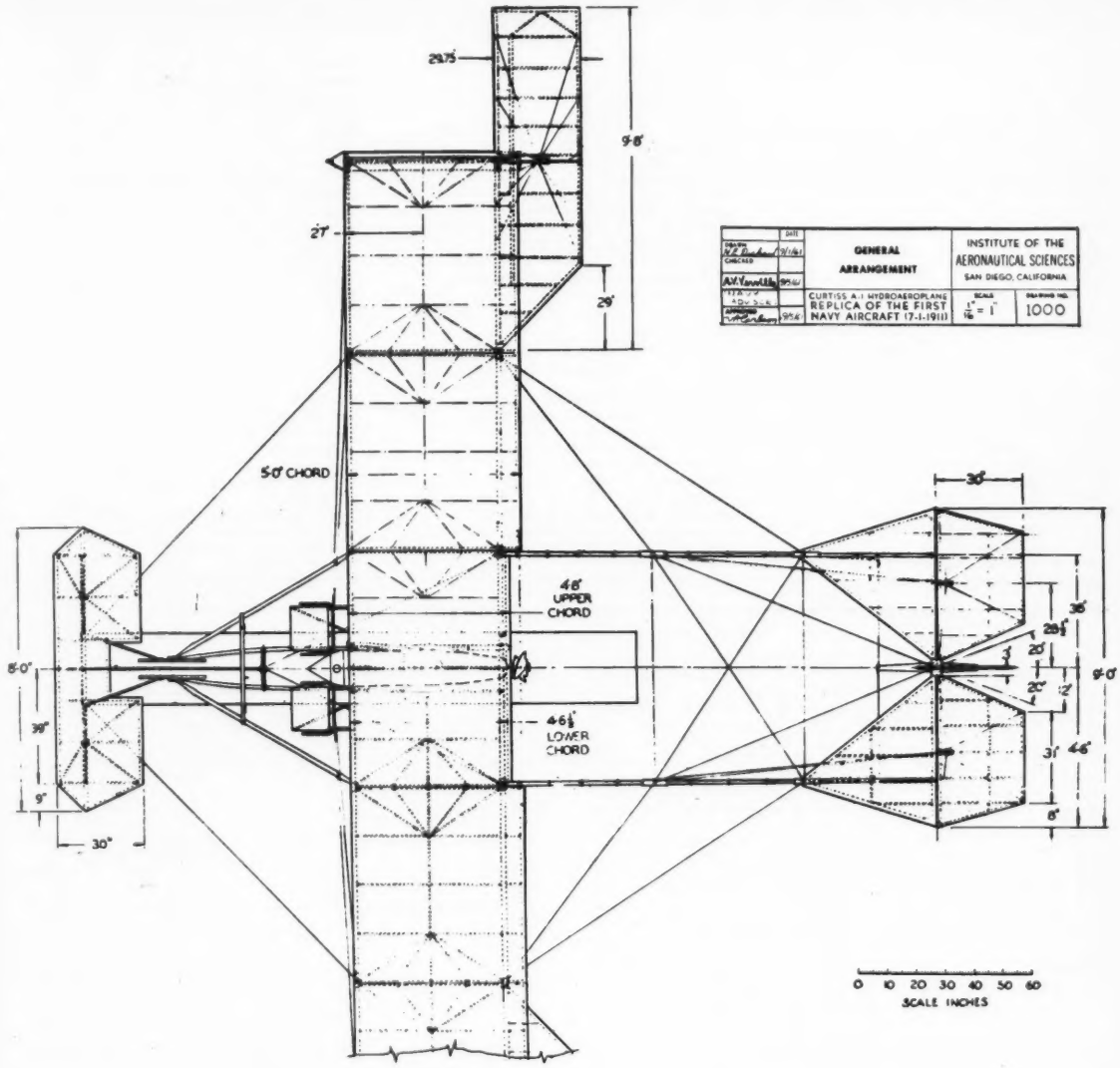
***Type:*** single-hull biplane. ***General dimensions:*** length, 27 ft 8 in.; height, 9 ft 4 in.; overall span, 37 ft; hull, 16 × 2 × 1 ft; displacement, 28.4 cu ft; total displacement, 1,770 lbs (fresh water), 1,820 lbs (sea water). ***Wing cellule:*** airfoil section, Curtiss-Voisin; angle of incidence, 7°; chord (upper and lower), 5 ft; gap, 5 ft; wing span, 28 ft 8 in. (upper and lower); wing area, 141 sq ft (upper), 140 sq ft (lower); total wing area, 281 sq ft; aspect ratio, 5.73. ***Control-surface areas:*** ailerons, 25 sq ft each; rudder, 9 sq ft; stabilizers, 8.5 sq ft each; elevators, 8.2 sq ft each; header plane, 16.6 sq ft. ***Power plant:*** Curtiss model "O" 8-cyl. w-c engine; 75 hp at 1,250 rpm; weight complete with prop. hub, dry, 350 lbs; fuel consumption per hp-hr, 0.6 lbs; oil consumption per hp-hr, 0.3 lbs; propeller (laminated wood) diam., 7 ft 9 in.; radiator core, $h = 26\frac{3}{8}$, $w = 14$ in., $d = 4$ in. ***Weights:*** gross weight, 1,575 lbs; weight empty, 1,065 lbs; useful load—gas, 120 lbs (approx.); oil (engine oil reservoir), 30 lbs; pilot, 180 lbs; passenger, 180 lbs.

Engine-starting procedures were checked with the aircraft stern-first on the beach. This was without the beaching cradle. A canvas pocket with an attached shock cord was slipped over the propeller tip and used to pull the propeller through smartly for engine start. Normal "propping," by rotating the propeller by hand, was too dangerous because of the maze of wires, cables, longerons, and the float in the immediate area. During the first taxi operation, at a water speed of 8–10 knots, the bow of the float started digging in below the water surface. Further speed increase would have caused a "stubbed toe," "flip-on-your-back" operation.

To counter this adverse characteristic, caused by the high thrust line, we reballasted to 35 percent M.A.C. The aft c.g. change improved elevator power and reduced float low-speed submersion characteristics. This solved the problem but made the "bird" more unstable.

Lateral stability with the modified wing-tip floats was satisfactory while taxiing in cross winds of 8–10 knots (Fig. 9). A passing boat wake went through the propeller disk in the float area, dropping rpm about 20 percent. No damage or serious eroding of the metal-tipped Sensenich propeller was evident later.

JULY 11TH—After tightening of the rigging and the elevator control cables and rechecking the c.g. and ballast, the replica was ready for high-speed taxi tests. A high-speed taxi run to approximately 35 knots was completed. As predicted, low-limit porpoising occurred at about 30 knots. Increasing the angle of attack with up elevator damped out this ad-




verse characteristic. No serious problems were encountered because of spray, engine overheating, or coolant leaks.

*First Flight*—After a normal launch, high-speed planing characteristics were checked-close to lift-off speed. Power was then advanced to full throttle for lift-off. Some torque was evident but readily controllable. The aircraft had a strong tendency abruptly to "jump off" the water. An immediate aircraft nose down elevator input was required to prevent a premature stall. Lift-off speed was roughly 45 knots. Elevator response was satisfactory. Balance in the air was perfect (Fig. 10). Considerable airframe vibration occurred above 800–900 rpm. The landing wires were quite slack in flight but did not appear to be excessively so. A partial power-on landing was made without incident. Deceleration characteristics were normal in all respects, with no undue porpoising tendencies.

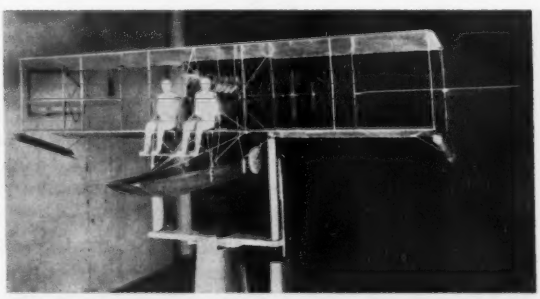


Fig. 4. Three-quarter front view of the model mounted in the tunnel for testing.

## Table 1. Curtiss A-1 Club

### *Honorary Members*

Alexander, George
Astrup, Fred
Bent, Ralph
Borthwick, Anderson
Buchanan, Ballard L.
Christopher, Wm.
Cline, J. C.
Coates, RADM. W., USN
Collins, Capt. W. M., USN
Dexter, R. R.
Ekstrom, VADM. C. E., USN
Elliott, R. W.
Evans, Hall
Fickes, K. L.
Forward, James D., Jr.
Garber, Paul
Gray, Allen
Harris, Anthony
Hoffman, Graydon
Johnston, S. Paul
Kait, Capt. H. H., USN
Krulak, Maj. Gen. V. H., USMC
Kunzel, Herbert
Locke, F. W. S.
Loeser, CDR O., USN (Ret.)
Morse, R.
Pickle, Lt. Col. K. B., USMC
Pirie, VADM. R. B., USN
Richardson, Capt. N. R., USN
Rohr, Fred H.
Ruckner, RADM. E. A., USN
Russell, ADM. J. S., USN
Ryan, T. Claude
Sefton, Thomas W.
Smith, C. Arnholt
Stalker, M. S.
Stever, H. Guyford
Stroop, RADM. P. D., USN
Stutzman, David
Sudsbury, Elretta
Sullivan, James
Tagmyer, Wm. C.
Washburn, Lou
Waterman, Waldo
Wells, James

### *Corporate Members*

Air Associates, Inc.
Andrew Brown Company
Bank of America
Bendix Aviation
Brass & Copper Supply Co.
Clarks Supply, Inc.
David Taylor Model Basin
Ducommun Metals & Supply Co.
Ehmcke Sheet Metal Works
First National Bank
General Dynamics/Convair
Goodyear Aircraft Corporation
Goodyear Tire & Rubber Company
Gould Hardware & Machinery Co.
Harley-Davidson Motor Co.
C. J. Hendry Co.
C. F. Herrmann Co.
Humphrey Castings, Inc.
Langlais, E. F.
Lawrence Engineering & Supply
Marine Corps Recruit Depot
Northrop Institute of Technology
The Rattan Shop
Rohr Aircraft Corporation
Ryan Aeronautical Company
San Diego Trust & Savings Bank
Shultz Steel Co.
Solar Aircraft Company
E. J. Stanton & Son Lumber Co.
Sullivan Hardwood Lumber Co.
Tubesales
Union Title Insurance Co.
U.S. National Bank
Western Gear Corporation
Western Lumber
Young Radiator Company

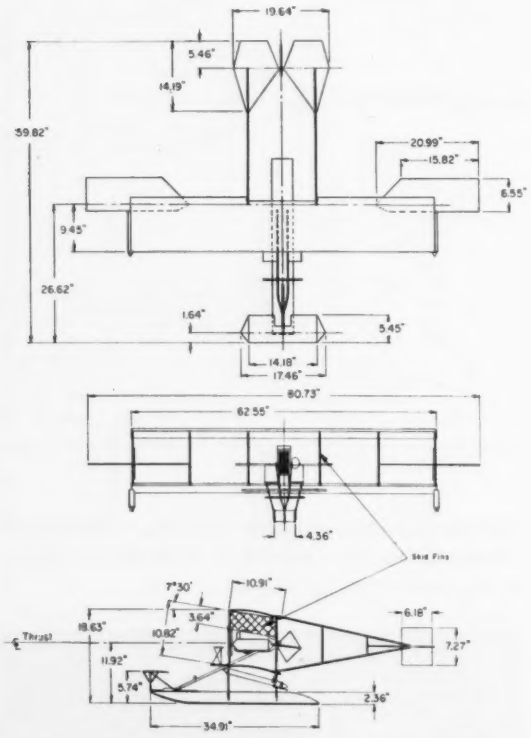



Fig. 5. Geometric characteristics and general arrangement of the model (prototype-to-model scale, 5.5 to 1).

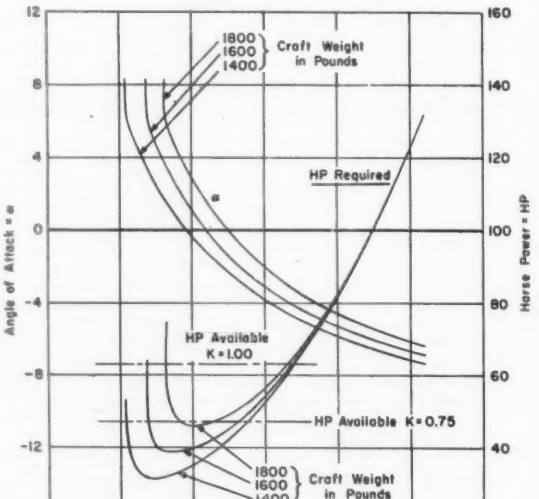



Fig. 6. Wind-tunnel model: hp and angle of attack vs. speed; tail plane at 0° to thrust line [hp available = $\eta K$ (bhp); $\eta$ = 0.70 (assumed); $K$ = 0.01 (percent power); bhp = 90 (Curtiss OX-5); bhp = 75 (Curtiss O)].

*Second Flight.*—A second short hop down the sea lane reached 20 ft of altitude. Power acceleration and deceleration traits were investigated. The aircraft decelerated rapidly when power was reduced. In case of engine failure a rapid nose-down maneuver is required to prevent inadvertent stalling. A partial-stall, power-on landing was made. The aircraft was taxied to the beaching area and the engine secured. Boat pickup was routine and the aircraft beached stern-first.

*Third Flight*—Routine launch and take-off. "S" turns were flown down the sea lane. Aileron-induced adverse yaw was quite high (the aircraft banked one

## Table 1. Curtiss A-1 Club (Cont.)

*Members*

Agnew, George—Design
Allen, Chase—Museum article float
Antoniak, Charles—Flight; Wing fabrication supervisor (Conning people out of their funds)
Arakawa, Roy—Fabrication
Bader, F. C.—*
Balke, Martin R.—*
Barkley, W. B.—Hydrodynamics analysis
Basich, George—Design
Bechtold, Percy—Fabrication
Beck, Theodore—Design
Beddoes, C. E.—Weights
Benson, Allen—Project Engineer
Benstead, Roy—Fabrication
Berlin, E. D.—Technical
Booker, C. J.
Bowman, Robert—Fabrication
Braun, C. A.—Design
Breitenbach, Max—Fabrication
Brickson, Francis—*
Briese, R. C.—*
Brown, W. F.—*
Carlson, Tony—Assisted with launching
Carlson, V. A.—Project Engineer
Carter, W. V.—Design
Claverie, A. W.—Fabrication
Cockrell, Peggy—Fabrication
Cockrell, W. S.—Manufacturing Supervisor
Coha, A. P.—Fabrication
Creel, R. L.—*
Cross, Timothy—Fabrication
Davis, Brig. Gen. L. L., USMC (Ret.)—Wing and tail fabrication (Tremendous number of hours)
Dirks, LTJG. C. L., USNR—Technical
Dixon, RADM. R. E., USN (Ret.)—Technical
Doerr, Donald—Fabrication
Dossey, Wm. C.—Fabrication
Dress, L.—*
Duncan, Capt. G., USN—Technical
Engel, Albert J.—*
Engel, Paul H.—Design
Engle, R. A.—Fabrication
Falgout, P. S.—Fabrication
Farmer, George—Technical
Fiari, W N.—Fabrication
Fife, Ray—Fabrication
Flint, Wm.—Fabrication
Fresh, J. Norman—Fabrication
Friend, Carl—Technical
Germeraad, D. P.—Pilot
Gill, Capt. Paul, USN—Technical
Glaubius, W. A.—Technical
Goosen, LCDR. E. D., USN—Technical
Gruessing, L. J.—*
Guske, Ed—Design
Gustavson, Al—*
Hallett, Maj. Geo. E. A., USA (Ret.)—Technical
Hamann, Dick—Fabrication
Haupt, Lt. H. S., USMC—Fabrication
Hopkins, John W.—Fabrication
Hopkins, Marguerite—Fabrication
Hopps, R. H.—Technical
Horne, Milton—Assembly
Horner, W. D.—*
Hull, Lawrence—Fabrication
Hunter, John—Fabrication
Immenschuh, Wm. T.—Project Director
Irvine, CDR. J. F., USN—Technical
Jacobson, Wm. H.—Weights
Jenson, Jack—Stress analysis and flight float
Kelly, Irvin—*
Kirk, Frank H.—*
Kleckler, Henry—Technical
Koster, Harry—*
Kourbelas, Nick—*
Kremzier, Emil—*
Landgraf, Fred—Control system design
Lankard, Robert H.—Fabrication
Lavato, M. L.—*
LeVine, Joe W.—*
L'Hollier, L. H.—Technical
Logan, Wm. D.—Administrative Engineer
Lokey, Robert—*
Mason, James—Design
McNair, S/Sgt. J. R.—Marine Corps model shop
Meixner, W. A.—Fabrication
Mendonca, John—*
Mooney, Walt—Fabrication
Murphy, Richard—*
Navoy, Anthony—Fabrication
Navoy, Helen—Fabrication
Nelson, Harold—*
Nelson, H. O.—*
Newcome, George—*
Oberg, A. B.—Strut and braces (wooden)
Opella, Tom—*
Pall, Francis—Design work (probably more hours than anyone)
Parker, Harry E.—Fabrication
Parrot, R. R.—*
Pazmany, Ladisloo—Design
Pearson, L. M.—*
Peck, R. E.—Technical (also assisted with outside donations)
Perkins, J. L.—Fabrication
Piszkin, Stanley T.—Lateral-directional stability and control
Ramstead, James—Fabrication
Reynolds, RADM. R. M., USN—Technical
Richards, Wm. P.—Design
Robbins, L.—*
Roberts, D. E.—Technical
Robischon, E. W.—IAS executive
Roby, John—Tail surfaces construction supervisor
Roman, Eugene—Design
Ryan, E. M. —*
Sakamoto, Norman—Fabrication
Schaefer, Wm.—*
Schnaubelt, F. J.—Design
Schoech, RADM. W. A., USN—Technical
Scott, John F.—Design
Segna, Donald—Technical
Service, Wm.—Fabrication
Shields, R. L.—*
Shipps, Paul—Fabrication
Shucker, Courtney—*
Sigler, Dale B.—*
Spurgeon, James—*
Staley, Ruth—Administrative
Stetsuk, G. M.—Fabrication
Tanner, Kurt—*
Templin, Anthony—Fabrication
Thomas, Del W.—Design
Trexel, John E.—Fabrication
Trusk, D. L.—Fabrication
Trusk, Roger—Fabrication
Turner, J. E.—Fabrication
Tuttle, Don—Design
Underhill, C. M.—*
Van Wyen, A. O.—*
Vasques, Terry—Dynamic and longitudinal stability and control
Verville, A. V.—Technical
Walacavage, Robert—Fabrication
Wallace, J. A.—Design
Wallace, J. L.—Design
Wasilewski, R. H.—Design
Ward, K. E.—Propeller design
Weber, W. B.—Aircraft performance prediction
Weldon, A. W.—*
Wenzel, J. G.—General Chairman
Westbrook, Robert—*
Williams, R. M.—Design
Winfield, Glen—Fabrication
Winfield, Palmer—Fabrication
Wollner, B. C.—Loads, Technical
Yoder, Richard—Fabrication

* Personnel who contributed to program, but whose specific effort is not known at the time of this printing.

way and would have turned the other if not for rudder inputs). Rudder effectivity was rather low, with large displacements required for turns. The yaw string and the glider-type airspeed indicator worked out quite well. A stall landing just above the water indicated adequate elevator control for a dead-stick landing. No stall buffet was evident. The aircraft pitched down rapidly at stall. Nothing was unusual here other than a requirement for windshield wipers on the goggles and a dry diaper!

*Fourth Flight*—Normal take-off and climb to 100 ft of altitude. A race-track pattern around the

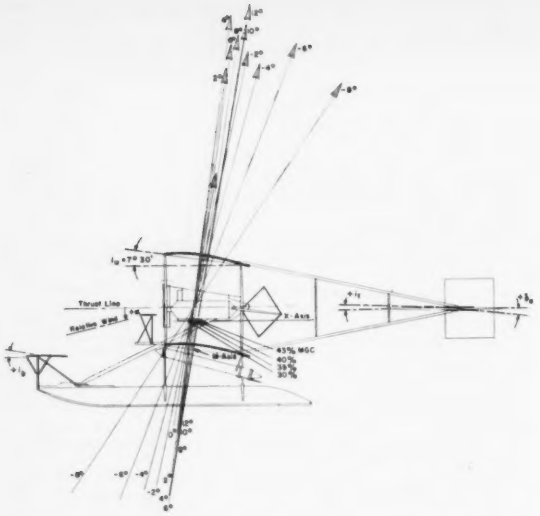


Fig. 7. Wind-tunnel model: line of resultant air force at 62 mph; tail plane at 0° to thrust line, elevator at 0°.

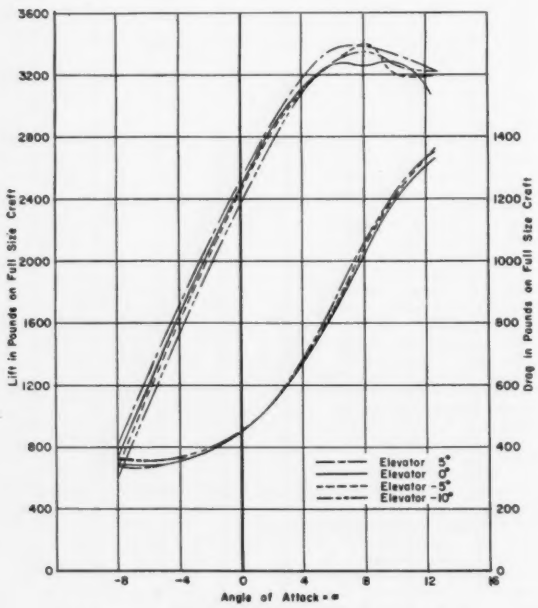



Fig. 8. Wind-tunnel model: lift and drag at 62 mph.

south bay seadrome was completed. Maximum speed reached was roughly 50 knots. The aircraft, basically unstable, required constant attention in flying and maneuvering, but it was not too difficult to do so. Aerodynamic centering of the control surfaces was poor due to high cable tensions at neutral settings. This was still more desirable than having considerable slack in the cables when the controls were displaced, as this was a nonlinear control system. A normal power-on landing completed the operations. No engine or propeller problems were encountered.

The aircraft was considered to be in flight readiness for the Fiftieth Anniversary of Naval Aviation Air Show the 19th and 20th of August, 1961. It was planned to conduct a short check-flight prior to the show, to insure engine and airframe operating capabilities.

AUGUST 18TH—*Fifth flight*—The aileron cable tension was increased before the flight. Normal launch and take-off. The glider-type airspeed indicator failed to indicate. Engine tachometer was now working OK. Idle rpm varied from 625 to 800. Take-off rpm reached 1,440 maximum. Cruise rpm were 1,340 at 50 knots I.A.S. Engine operation was excellent except for vibration. Two circuits of the South Bay seadrome were completed, including a "press" fly-by.

One helicopter passed directly in front during the final landing approach. Full power and full lateral and directional control inputs were required to counter the rotor wash. (This was a passing helicopter and was not one of the three that participated in the operation.) Landing and recovery were routine.

The fuel used was checked carefully to obtain data for the Air Show flight-pattern fuel requirements. Calculations showed adequate reserve for the mission. All was in readiness for the Air Show commitments, weather permitting.

AUGUST 19TH—*Sixth flight*—Air Show flight pattern to Shelter Island and return completed per schedule. What a panoramic view of San Diego! (Fig. 11). No serious discrepancies other than airspeed-system failure during take-off. Immediately resorted to emergency "seat of the pants" back-up system.

AUGUST 20TH—*Seventh flight*—Air Show commitment repeated on schedule despite gusty winds which made flying difficult. The airspeed indication fluctuated from stall speed (39 knots) to $V_{max}$ (52 knots) in the Shelter Island area of the Bay.

This flight completed the replica A-1 operations. From pilot to support crew—a hearty "well done!" Cdr. J. Irvine and Ray Fife deserve the credit for keeping operations running smoothly without a hitch.

### Flight Characteristics

The flight characteristics of the A-1 can be summarized briefly.

(1) Spiral instability.

(2) Handling characteristics in coordinated turns are quite poor, due to large adverse yaw effects caused by the lifting-type aileron.

(3) Static directional and lateral stability is almost nil, requiring constant pilot attention to maintain a given attitude. If the controls are released, the aircraft tends spirally to dive, climb, or roll. The A-1 does *not quite meet* the present FAA regulations.

(4) Control forces are poorly balanced; the high

lateral and low directional control forces result in way-below-par harmony.

(5) Added power is stabilizing, since the thrust line is above the c.g. and the normal force line aft of the c.g.

(6) The power-off characteristics leave much to be desired. The minimum glide angle is approximately 10°–12° and the rate of sink 800–900 ft per min (airliners use a 3° glide slope). Although the wing loading is low (5 lb/ft$^2$), the L/D ratio is also quite low (~5) as compared with a high-performance sailplane (~35).

This "bird" has many advantages for a pilot. You can't beat the cockpit visibility! (Fig. 8). That is, if you can focus on anything because of the vibration! No problem with air conditioning either—other than adjusting the flow. Performance is startling, with a cruise speed of Mach 0.073 or about 50 knots.

Instrumentation is simple. A cruciform on the foremast is a pitch indicator. If the engine overheats and starts steaming, a radiator line down to the float gives the pilot a "hot foot." A piece of yarn tied to the foremast becomes an excellent yaw indicator. However, if it blew off, the wind on either cheek would do just as well.

The real beauty about flying the A-1 is ye olde Curtiss OX-5 engine. That 5 "OX" power is worth 90 horsepower and it chortles like a kitten. It is a real treat to be seated in front rather than behind this engine so that your goggles are not dripping with oil from the engine or glycol from the radiator. My wife suggested that I wear a long silk scarf. I think she did this deliberately since it would fly back in the propeller and there would be a different type of throttling operation!

After a normal turn around the pattern on this "relaxing machine" you really anticipate the landing with relish. Don't let a little water dampen your spirits on touch-down. After the first operation I felt everyone was just too polite to ask if my wet coveralls were an inside job.

This aircraft is quite modern in one respect! Beside me in front of the radiator is a black box. Its components have far better reliability than our present-day flight director units. You see, the white lines inside this black box are used for mooring the aircraft instead of carrying electronic signals to a computer.

After receiving President Kennedy's recent edict, "... be prepared on all counts," the Overhaul and Repair Department, North Island, can quickly mount a Side Winder on either wing tip. The A-1 could be combat ready once again to join the Navy's proud fleet!

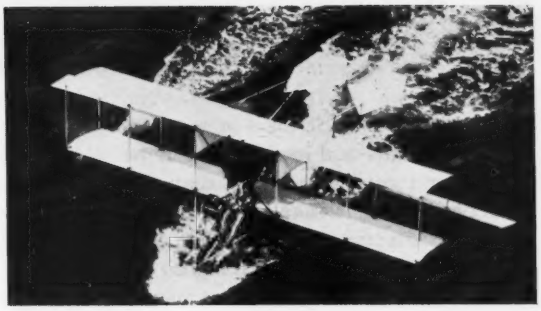


Fig. 9. A-1 replica taxiing.

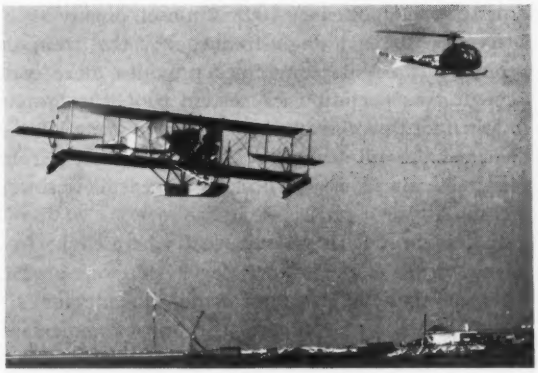


Fig. 10. A-1 replica airborne.

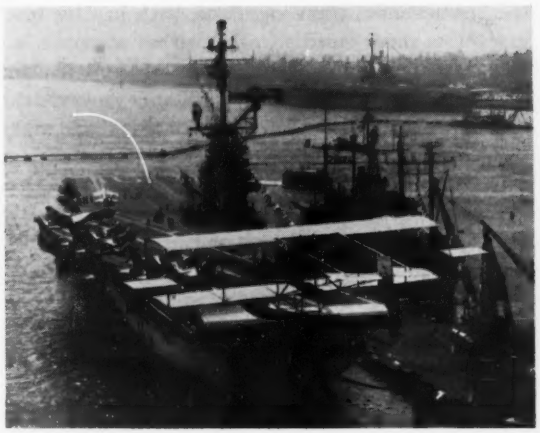


Fig. 11. A-1 replica in flight, Aug. 19, 1961.

## References


[1] *Aviation Log, Curtiss Hydroaeroplane, Navy No. A-1, 1 July 1911 to 16 October 1912.*

[2] Fresh, J. N., and Murphy, R. D., *Commemorative Reports on the A-1 Hydroaeroplane for the Golden Anniversary of Naval Aviation,* David Taylor Model Basin, Aero Rep. 1000, May 1961.

[3] *Aviation Log, Curtiss Hydroaeroplane, Navy No. A-1 Replica, 1 July 1961 to 20 August 1961.*


✦ ✦ ✦

## Short-Haul Air Transportation

(Continued from page 25)

both in pounds and in dollars, will be sold in the future for short-haul services than for other types of service—*if a substantial breakthrough in vehicle operational suitability* can be made to provide more convenient travel for those using air transportation.

Some of the heaviest traffic segments are shown in Fig. 3; note that on all of these segments high-frequency service is provided. On the New York–Washington segment the average service is in the order of one flight every 10 min in each direction.

Even with such high frequencies, the train or private automobile sometimes provides more convenient transportation for certain people, considering the fact that the automobile can go from door to door and the railroad train, of course, operates from terminals which are often close to central business areas.

In less heavily traveled areas, where flight frequency drops to much lower levels (like one or two flights a day), it becomes more difficult for air transportation to provide the most convenient service. A persistent problem is that the surface transportation phase of the trip often takes longer than the air transportation phase.

An important person in the short-haul picture is the businessman, traveling alone, with just his brief case or a small suitcase, who wishes to make his trip in a minimum length of time. He often plans to get quickly to a city 200 or 300 miles away, take care of his business in a few hours, or a day, and make a quick return trip. This traveler is more impatient with delays than the long-haul air traveler, who has frequently allocated a full day for his trip.

The short-haul traveler often considers travel cost less important than time saved for his business activities. He will be most impressed by convenience and a minimum number of disturbing delays.

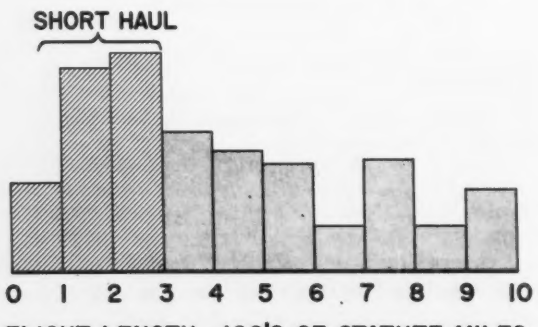



Fig. 2. Distribution of the short/medium haul portion (70+ percent) of the supply of U.S. domestic airline seat-miles.

| | FLIGHTS PER DAY |
|---|---|
| NEW YORK - WASHINGTON, D.C. | 219 |
| NEW YORK - BOSTON | 170 |
| NEW YORK - BUFFALO | 37 |
| CHICAGO - DETROIT | 72 |
| CHICAGO - ST. LOUIS | 60 |
| CHICAGO - MILWAUKEE | 60 |
| CHICAGO - INDIANAPOLIS | 44 |
| CHICAGO - CINCINNATI | 38 |

Fig. 3. Number of flights daily on some of the most heavily traveled short-haul segments.

"Availability" will play an important role in the short-haul traveler's decision regarding his transportation. He will be impressed by flight frequency, because this will affect "availability" of the "next flight," and he will be conscious of surface transportation time to the terminal and the airport. Noise, seating comfort, food service, and other "acceptability" factors may be of less importance than the availability, convenience, and timesaving factors in this type of service.

One of the basic reasons for failure to solve short-haul transportation problems is that coordination of effort is required. There is growing recognition of this fact. Recently, a report issued by the Golden Gate Authority Commission in San Francisco recommended creation of a Master Regional Agency to coordinate the Bay Area's bridges, seaports, airports, and rapid transit system. Further, on February 21 of this year, the Southern California Research Council recommended that a Master Plan Transport Authority be established to coordinate all phases of Southern California's transport picture including highways, airports, and rapid transit.

The New York City agencies are, of course, well known, and coordinating agencies are active in Chicago and other large cities.

It is obvious that short-haul transportation involves piecing together several components of a transportation system. The air transport component may be one of the least troublesome portions of the overall problem. It may develop that more gains will be made in the process of providing for the passenger from the time he enters a surface transportation vehicle until he enters an air vehicle than in any other phase of the overall system.

One of the difficult factors hindering progress in short-haul transportation is the cost of this service, in spite of what was said earlier about the importance of other factors. Since the distances are short, the traveler does not expect to pay a large amount for

his ticket; but the situation is such that, in order to just cover costs, he must pay much more per mile than for long-haul transportation because many of the costs are associated with the beginning and ending portions of the trip and are, to a certain degree, fixed costs per trip unrelated to flight length. In addition, if true improvement in convenience of short-haul travel is to be made, it will be necessary to spend fairly large amounts of money in developments involving improved air vehicles, buildings, and equipment used in connection with providing this service. However, surface transportation costs per trip should be lower because of shorter distances to the airports. This would tend to counteract higher air vehicle operating costs.

### Challenging Technical Problems

It is suggested that in order to take a big step forward, it will be necessary to use a "system" approach to short-haul transportation. To visualize the goal perhaps we should consider the situation as pictured in Fig. 4. Several groups will be enlisted in working out an overall solution. Also, a number of technical fields will be involved, including architectural engineering, control and communication equipment design, airport engineering, and, of course, air vehicle design. In the case of small communities, where distances are shorter in most instances, less activity will be required insofar as new ground facilities are concerned.

The agency concerned with surface transportation will wish to review the operating characteristics of the vehicles used and the roads or rails on which they travel to air terminal areas, in an attempt to improve this phase of the service. Also, changes will be indicated, in an overall "system" review, to integrate the surface systems into the overall short-haul transportation system, especially in order to shorten the passengers' walk between vehicles.

With regard to an air vehicle suitable for short-haul service—some of the aircraft now available provide a relatively low level of operating cost which will be hard to match in years to come. And at least one manufacturer is talking about a two-engine turbofan-powered airplane, with about 50 seats, which would provide high cruise speed performance. This is helpful insofar as passenger appeal is concerned but is not translatable into as much time-saving on short-haul flights as it is in the case of long-haul flights.

Since short-haul service involves a need for great operational flexibility and short landing and take-off performance permits use of close-in airports, it is believed that at some point in the future the state of the art will have advanced sufficiently to make a VTOL vehicle practical for short-haul operation. In an analysis of the operating costs of two 50-passenger vehicles (one a twin turbofan type requiring 5,000-ft runways and the other a multiengine VTOL), it was noted that the price of the vertical lift vehicle was higher, which affected the depreciation and the insurance costs; the fuel costs were higher because of the extra thrust required during the landing and take-off operations; and the engine maintenance costs were higher because of the larger number of engines. However, some of these higher costs were balanced by shorter flight time as the result of the elimination of most of the maneuvering requirements in the air and on the ground at the beginning and end of the flight. Considering the great improvements in convenience which can be realized in some locations through maximum use of the VTOL capability, a moderate difference in the air vehicle operating cost (about 30 percent at 150 miles) should not be an obstacle, particularly if surface transportation costs can be reduced. The question really rests with the community, which should adapt its airport and terminal facilities so that maximum benefits can be realized from use of VTOL machines. This applies specifically and most importantly to the large cities from which "radial" service emanates. New York, Chicago, Los Angeles, and San Francisco are examples of such cities, of course.

Selection of a suitable size for an air vehicle for short-haul service is a key consideration—too large a capacity will result in infrequent service, and too small a vehicle will not have reasonable seat-mile costs. Since we shall probably be dealing with larger communities for a short-haul transportation "system," it is expected that a suitable vehicle would have at least 60 to 80 seats; but this should be the subject of careful analysis.

It will be desirable to work out the operating characteristics—especially approach, landing, and take-off characteristics—with the air carriers involved. They will also be interested in service features and such physical characteristics as cabin width, door size, aisle width, seating density, and the many other design elements involved in optimizing a transport vehicle.

One feature of a new vehicle necessary to provide

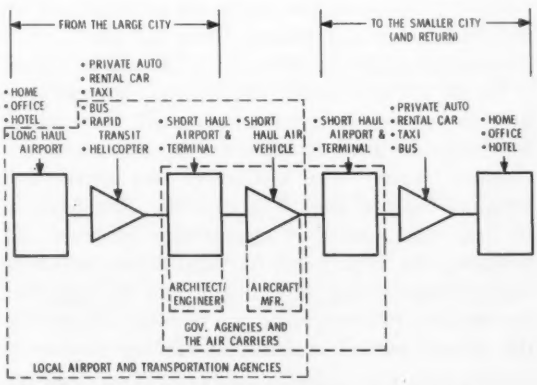



Fig. 4. Coordinated effort is required to minimize trip time.

convenience for the traveler will be all-weather capability. This will call for much effort on the part of the aircraft manufacturers, the designers of communication and control equipment, the FAA, the airport people, and others.

Many will say that the most serious factors affecting the growth of short-haul air transportation are congestion and the related capability of air traffic control to handle a large increase in the number of air vehicles arriving in or departing from large metropolitan areas.

There are two simplifying factors associated with the use of VTOL vehicles for short-haul services. The first results from the fact that the VTOL vehicle can operate at slower speeds, can make smaller radius turns and steeper descents and ascents, can therefore operate in a much tighter pattern, and will, in all of its operations, use a smaller amount of air space. The second simplifying factor is concerned with the reduction of the burden on air traffic control at airports handling medium-haul and long-haul aircraft. This will result from transfer of short-haul activities to a more centrally located short-haul airport terminal.

However, a complicating factor is the addition of another airport in a given metropolitan area. It is thought that, in order to be most useful, in large cities the short-haul vehicle should land at a central location served by rapid transit trains, buses, taxis, rental cars, private automobiles, and helicopters. Thus, an extra airport is involved in the accompanying air traffic control complications.

A second complicating factor is also related to improving short-haul travel for the passenger. It is believed that there should be several corridors for approach to and departure from the short-haul terminal rather than (for instance) just one corridor. Having several corridors will permit timesaving "straight-in" approaches from many different cities located in various directions. Also, multiple, simultaneous landings should be possible, when necessary.

There will thus be some simplifying factors and some complicating factors. It is likely that short-haul service cannot be improved without adding complexity. However, a VTOL vehicle will have operating characteristics which will make some of the air traffic control problems easier to solve. It is expected that these problems can and will be solved.

To use a VTOL vehicle effectively in large cities, a new airport and terminal building will be required, especially designed to improve the operation on a "system" basis. The location of this airport and terminal building should be carefully considered to tie into the surface transportation systems. In designing the airport and terminal areas, the architectural/engineering firm might find it desirable, for instance, to incorporate in a building adjacent to the airport surface a series of loading platforms, each one underneath the other. One of these could be for private automobiles and taxicabs, another for rental cars and buses, and a third for rapid transit trains. The VTOL vehicle and/or its passengers might logically be mechanically delivered to each of these platforms in turn, in order to permit quick and easy transfer of the passengers to a desired surface transportation vehicle.

A considerable amount of effort is also required to minimize any delaying factors in the system, such as ticketing for the air flight, renting a car, or paying bus fare.

It is obvious that the smaller communities will not be able to afford all of the timesaving features installed in the large city terminals. However, as time passes they can review their requirements for improving services and allocate necessary moneys for improvements as desired.

Considering the need to concentrate on timesaving in the short-haul operation, it is believed that the aircraft designer and the terminal designer should strive to keep the system compact to avoid any need for the passenger to walk or be transported an unnecessary distance. For this reason one might envision a terminal building and unloading areas arranged vertically rather than spread over acres and acres of ground. Furthermore, as one approaches the center of large communities, the limited availability and high cost of real estate dictate the vertical use of surface areas.

### Organizational and Administrative Planning

Although there are many difficulties associated with designing a suitable air vehicle for VTOL operation into and out of a large city, some of the other problems in providing a wholly integrated system and a suitable terminal may be even more difficult. It is, therefore, suggested that planning should proceed on the basis of anticipated vehicle characteristics. In this way planning can proceed while suitable machines are being designed.

It is desirable to look for an "interested party" to allocate money and initiate action which will lead to the system design covering short-haul transportation. Many transportation companies and various federal and local government groups are interested in improving transportation. However, the most interested group may be the businessmen, planners, and city officials in the large city who are striving to promote commercial activity in the central metropolitan areas.

If this is true, we may find that a large city's planning group will set up a working committee that includes the transportation agency, an architectural/engineering firm, the air carrier or carriers concerned, and an aerospace firm with systems design and systems management experience.

✦ ✦ ✦

## Gas-Floated Spinning Spheres

(Continued from page 27)

torque produced by a segment of an equatorial belt extending from a latitude of $\beta = -\beta_0$ to $\beta = +\beta_0$ and covering a longitude angle of $2\beta_0$. This drag torque, denoted by $T'_B$, is easily shown to be

$$T'_B = (2\beta_0/2\pi)\ (4\pi\mu\omega R^4/h)\ [\sin\beta_0\ (\cos^2\beta_0 + 2)/3]$$
$$= (4/3)\ \beta_0 \sin\beta_0\ (\cos^2\beta_0 + 2)\ (\mu\omega R^4/h) \quad (5)$$

For $\beta_0 = 30°$, Eq. (5) becomes

$$T'_B = 0.960\ (\mu\omega R^4/h)$$

A still better approximation is obtained by substituting the surface area of a spherical cup of angle $2\beta_0$ for the surface area of the belt segment, which was effectively used in deriving Eq. (5). It can easily be shown that the ratio $k$ (cup area to belt-segment area) is

$$k = (\pi/2\beta_0) \tan(\beta_0/2)$$

Multiplying the right member of Eq. (5) by $k$, a better approximation $T''_B$ is obtained.

$$T''_B = (2\pi/3) \tan(\beta_0/2) \sin\beta_0 \times (\cos^2\beta_0 + 2)(\mu\omega R^4/h) \quad (6)$$

which for $\beta_0 = 30°$ becomes

$$T''_B = 0.772\ (\mu\omega R^4/h)$$

By comparing this torque-coefficient value of 0.772 with the exact value of 0.788, derived from Eq. (14a) shown below, it is seen that this approximation is a good one even for circular pads as large as 60°.

Thus, the drag torque of an equatorial circular pad covering an angle of 60° is 7.15 times that of the same pad centered on the spin axis.

The exact expression for the drag torque of a circular pad is derived as follows. By referring to Eq. (1) it may be seen that the differential drag torque may be written

$$dT = (\mu\omega R^2/h) \sin^2\theta\ dA \quad (7)$$

where $dA$ denotes the differential surface area.

From Fig. 5 it may be seen that the differential area $dA$ is equal to $R^2 \sin\theta\ d\phi\ d\theta$. By substituting this expression into Eq. (7) the differential torque $dT$ for one pad becomes

$$dT = (\mu R^4\omega/h) \sin^3\theta\ d\phi\ d\theta \quad (8)$$

For the case where the centerline of a circular pad is coincident with the spinning axis, Eq. (8) is readily integrated to give the following expression:

$$T_{\text{polar pad}} = \frac{2\pi\mu\omega R^4}{3h}\left[2 - \left(2 + \sin^2\frac{\sigma}{2}\right)\cos\frac{\sigma}{2}\right] \quad (9)$$

When $\alpha \geq \sigma/2$ (Fig. 6), the integral expression

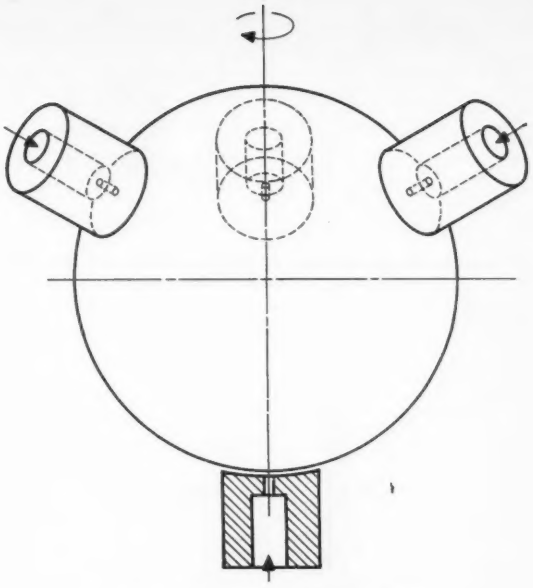


Fig. 2. Pad-supported spinning sphere.

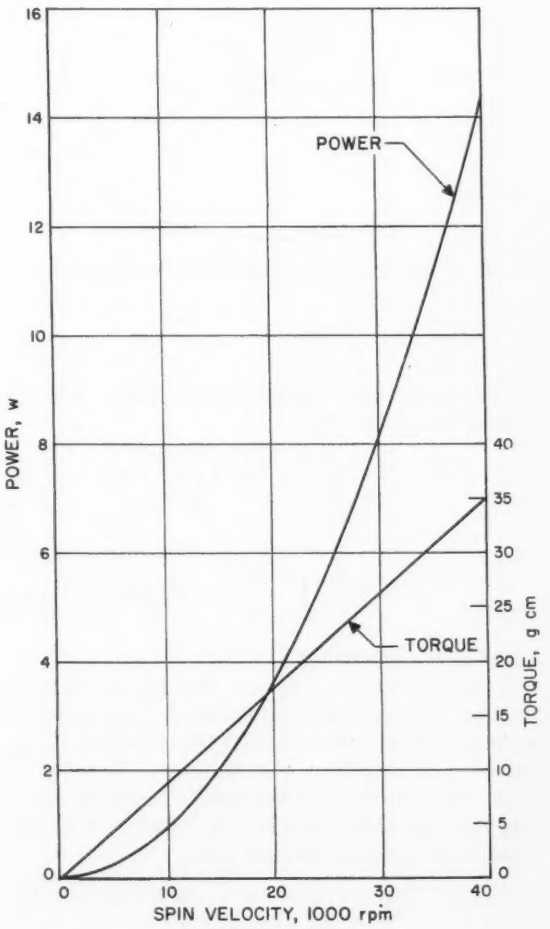



Fig. 3. Drag torque and power requirement for a 2-in.-diam. sphere spinning in a concentric shell; gas air, $h$ = 0.003 in.

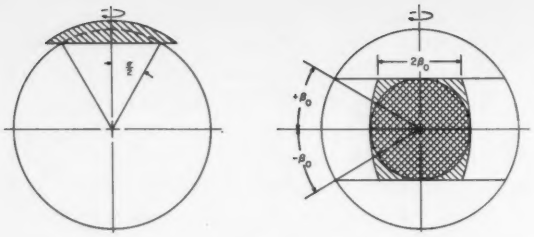



Fig. 4. Extreme pad positions on spinning sphere. (a) *Left:* Pad on spin axis. (b) *Right:* Pad on equator.

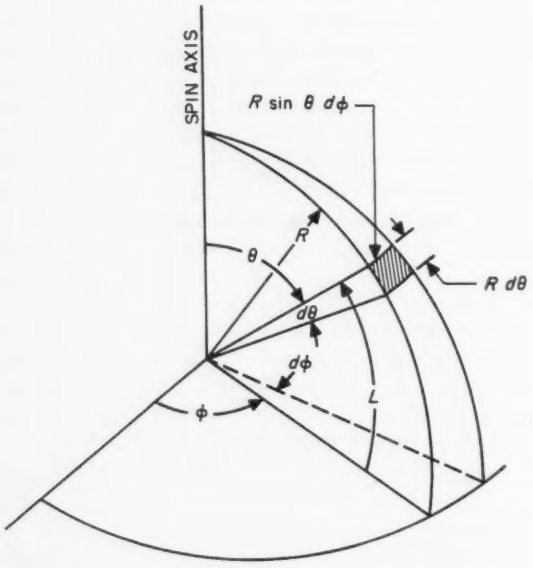



Fig. 5. Differential area of support pad for spinning sphere.

for the torque may be developed as follows: Integration of Eq. (8) results in

$$T = \frac{\mu R^4 \omega}{h} \int_{\alpha-\sigma/2}^{\alpha+\sigma/2} \sin^3\theta \left[\phi\right]_{-\phi_1}^{\phi_1} d\theta$$

or

$$T = \frac{2\mu R^4 \omega}{h} \int_{\alpha-\sigma/2}^{\alpha+\sigma/2} \sin^3\theta [\phi_1] d\theta \qquad (10)$$

where $\phi_1$ is a function of $\theta$, $\alpha$, $\sigma$.

With reference to Fig. 6, it may be seen that $\phi_1$ may be established by determining the point of intersection of the ellipse formed by the projection of the circular-pad boundary and the circle of radius $R \sin\theta$. Letting the spin axis be the origin of a rectangular coordinate system, the value of $x$ at the point of intersection is found to be

$$x = [R(\cos\sigma/2 - \cos\alpha\cos\theta)]/\sin\alpha \qquad (11)$$

$$\cos\phi_1 = \frac{x}{R\sin\theta} = \frac{\cos\sigma/2 - \cos\alpha\cos\theta}{\sin\alpha\sin\theta} \qquad (12)$$

$$\phi_1 = \arccos\left[\frac{\cos\sigma/2}{\sin\alpha\sin\theta} - \cot\alpha\cot\theta\right] \qquad (13)$$

By substituting this value of $\phi_1$ into Eq. (10), the integral expression for the torque produced by one circular pad becomes

$$T = \frac{2\mu R^4\omega}{h}\int_{\alpha-\sigma/2}^{\alpha+\sigma/2} \sin^3\theta \arccos Y \left[\frac{\cos\sigma/2}{\sin\alpha\sin\theta} - \cot\alpha\cot\theta\right] d\theta \qquad (14a)$$

Eq. (14a) represents the total torque produced by one circular pad when $\alpha \geq \sigma/2$. For $0 < \alpha < \sigma/2$, the integral of Eq. (14a) does not include a certain portion of the pad which is centered at the spin axis. The torque from this additional portion may easily be calculated by using Eq. (9). For these values of $\alpha$, the torque is given by

$$T = \frac{2\mu R^4\omega}{h}\left\{\int_{\alpha-\sigma/2}^{\alpha+\sigma/2} \sin^3\theta \arccos\left[\frac{\cos\sigma/2}{\sin\alpha\sin\theta} - \cot\alpha\cot\theta\right] d\theta + \frac{\pi}{3}\left[2 - \left(2 + \sin^2\left[\frac{\sigma}{2} - \alpha\right]\right)\times \cos\left(\frac{\sigma}{2} - \alpha\right)\right]\right\} \qquad (14b)$$

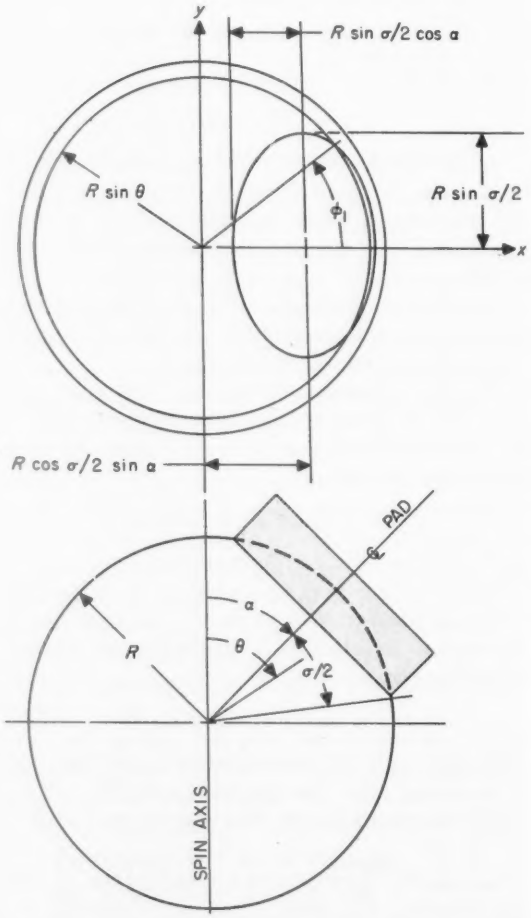



Fig. 6. Geometry for single-circular-support pad when $\alpha \leq \sigma/2$.

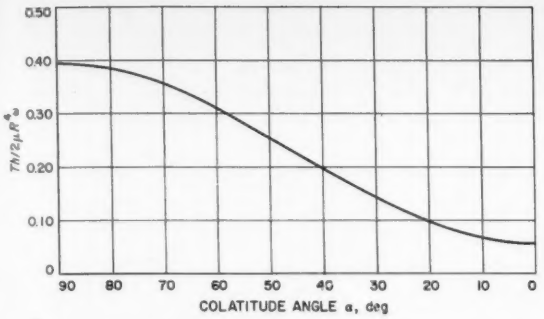



Fig. 7. Drag torque from one circular pad ($\sigma = 60°$) as a function of the colatitude $\alpha$.

By numerically evaluating Eq. (14), the exact drag-torque contribution of a circular pad of any size may be determined. Fig. 7 shows the drag torque of one circular pad ($\sigma = 60°$) plotted against the colatitude angle $\alpha$.

### Multiple-Circular-Pad Support Systems

Since the spin axis of a sphere may assume random positions with respect to the support-pad system, it is desirable to know what kind of circular-pad systems, if any, will have the property that the drag torque is independent of the spin-axis direction. Consider a circular pad of infinitesimal size whose center is spaced an angular distance $\alpha$ from the spin axis (Fig. 8). The differential drag torque $dT_c$, caused by this differential central area $dA_c$, is given by the following equation:

$$dT_c = \frac{\mu}{h} \overbrace{R\omega \sin \alpha}^{\text{Velocity}} \overbrace{R \sin \alpha}^{\text{Moment Arm}} dA_c = \frac{\mu\omega R^2}{h} \sin^2 \alpha \, dA_c \quad (15)$$

where $R$, $\omega$, $h$, and $\mu$ are, respectively, the radius, angular velocity of spin, uniform radial gap between sphere and pad, and the absolute coefficient of viscosity.

The drag torque produced by the central infinitesimal areas of $n$ distinct pads may be represented as follows:

$$dT_{cn} = \frac{\mu\omega R^2}{h} dA_c \sum_{i=1}^{n} \sin^2 \alpha_i \quad (16)$$

If

$$\sum_{i=1}^{n} \sin^2 \alpha_i$$

is equal to a constant for a particular pad system, then $dT_{cn}$ is independent of the spin-axis direction. Let the pad centers be located by the colatitude angles $\zeta_i$ and by the longitude angles $\psi_i$. Let the colatitude and longitude angles of the spin axis be, respectively, $\gamma$ and $\eta$ (Fig. 8). By forming the scalar product of vectors **P** and **S** (Fig. 8) it is easy to show that

$$\cos \alpha_i = \sin \zeta_i \sin \psi_i \sin \gamma \sin \eta + \sin \zeta_i \cos \psi_i \sin \gamma \times \cos \eta + \cos \zeta_i \cos \gamma \quad (17)$$

Thus, it follows that

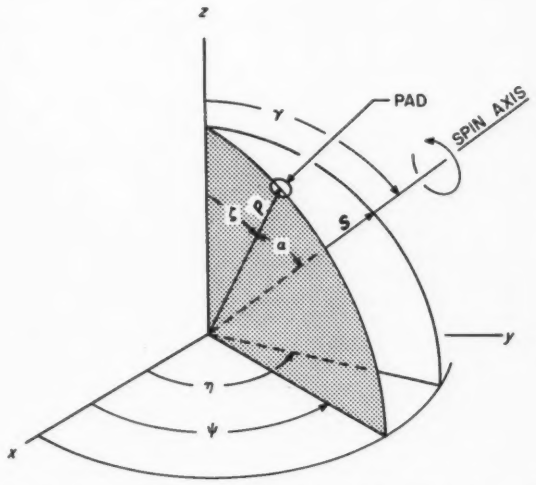



Fig. 8. True angle $\alpha$ between spin axis and line joining center of sphere to center of circular pad.

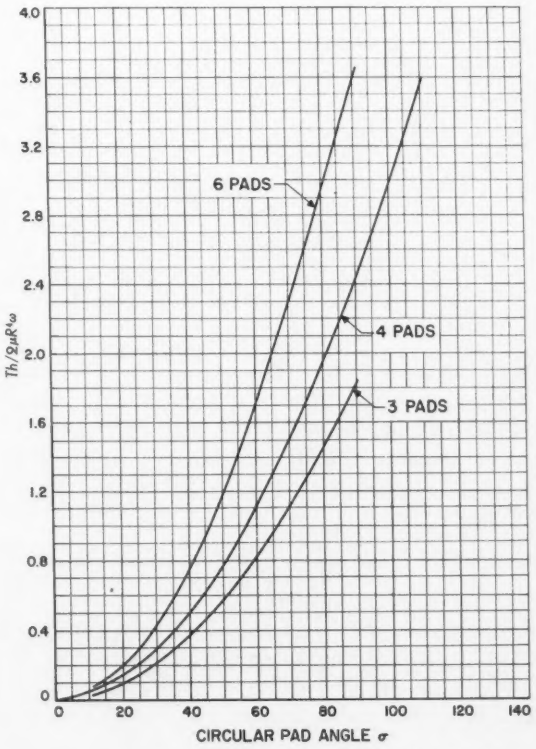



Fig. 9. Total torque of circular-pad systems where torque is independent of spin-axis direction.

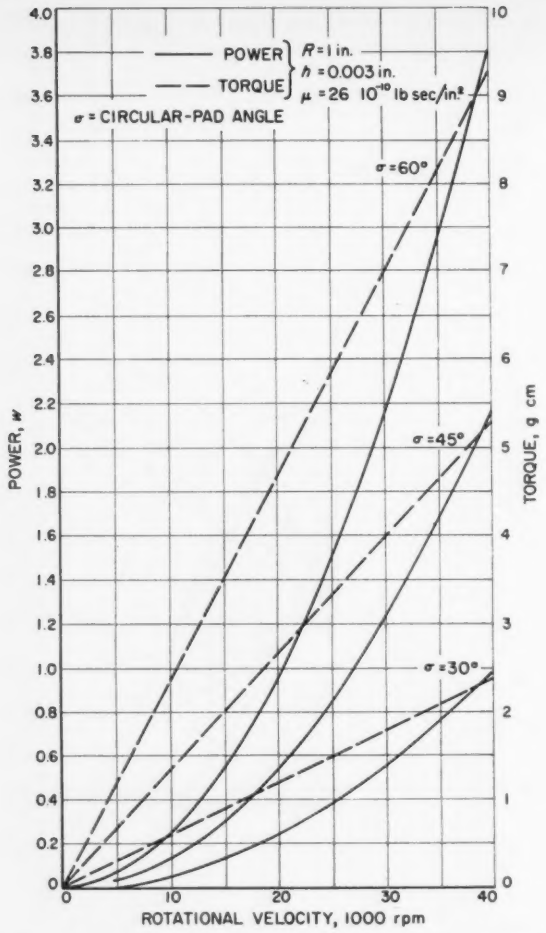



Fig. 10. Torque and power requirements for a four-circular-pad system as functions of rotational velocity.

$$\left.\begin{aligned}&\sin^2\alpha_i = \\ &1 - \sin^2\zeta_i \sin^2\psi_i \sin^2\gamma \sin^2\eta \\ &\quad - \sin^2\zeta_i \cos^2\psi_i \sin^2\gamma \cos^2\eta - \cos^2\zeta_i \cos^2\gamma \\ &\quad - 2\sin^2\zeta_i \sin\psi_i \cos\psi_i \sin^2\gamma \sin\eta \cos\eta \\ &\quad - 2\sin\zeta_i \cos\zeta_i \sin\psi_i \sin\gamma \cos\gamma \sin\eta \\ &\quad - 2\sin\zeta_i \cos\zeta_i \cos\psi_i \sin\gamma \cos\gamma \cos\eta\end{aligned}\right\} \quad (18)$$

By applying Eqs. (16) and (18) to any given pad system it may be learned whether that system's torque is independent of the spin-axis direction. As an example, consider a three-pad system with $\zeta_1 = 0$, $\zeta_2 = 90°$, $\psi_2 = 0$, $\zeta_3 = 90°$, $\psi_3 = 90°$, for which values

$$\sum_{i=1}^{3} \sin^2\alpha_i = 2$$

Another example is a four-pad system with $\zeta_1 = 0$, $\zeta_2 = 109°\ 28\ \text{min} = \text{arc sin}\ 1/3$, $\psi_2 = 0$, $\zeta_3 = 109°\ 28\ \text{min}$, $\psi_3 = 120°$, $\zeta_4 = 109°\ 28\ \text{min}$, $\psi_4 = 240°$, for which values

$$\sum_{i=1}^{4} \sin^2\alpha_i = 8/3$$

Hence, either of these systems has the characteristic that the torque caused by infinitesimal central areas is independent of the spin-axis direction. Also, any combination of multiples of these systems would have the same characteristics. Obviously, the drag torque of a one-pad system or of a two-pad system would not be independent of the spin-axis direction.

It may also be proved that there is a point-to-point correspondence between any infinitesimal areas of the aforesaid three- or four-circular-pad systems such that a set of corresponding points has the same relative spacing as the central points. These corresponding points are unique except for a finite number of exclusions. Thus, it follows that the drag torque from a spinning sphere supported on three or four circular pads of uniform size and gaps, and positioned as described above, will be independent of the spin-axis direction. Also, any combination of multiples of these systems will have the same property. The minimum number of pads (with this characteristic) which will contain the sphere against any direction of loading is four. Thus, the proper four-pad system would be arranged as in the example given above, which is equivalent to saying that each pad should be spaced 109° 28 min (measured on great circles) from every other pad. The next least number of pads which will completely contain the sphere and make its torque independent of the spin axis is six, a combination of two of the three-pad systems described in the above example. An obviously practical six-pad system would be one having diametrically opposed pads on each of three mutually perpendicular axes.

Eq. (14) has been evaluated by numerical integration for several values of $\sigma$ and $\alpha$. The reults as applied to circular-pad systems of the type described above and containing three, four, and six pads are plotted in Fig. 9. For these systems, where the drag torque is independent of the spin-axis direction, the dimensionless quantity $Th/2\mu R^4\omega$ is simply a function of the pad angle $\sigma$. The torque from any system of circular pads, which may be formed by combining multiples of the three- and four-pad systems, may easily be obtained from these curves by properly adding ordinate values.

As an example, Fig. 10 shows the drag torque and power requirement for a four-circular-pad system as a function of spin velocity for three different pad sizes. The other parametric values are $R = 1$ in., $h = 0.003$ in., and $\mu = 26 \times 10^{-10}$ lb-sec/in.$^2$. For the $\sigma = 60°$ system it may be seen that the power requirement and drag torque at 5,000 rpm are, respectively, 0.06 w and 1.17 g cm; at 40,000 rpm the values are 3.84 w and 9.36 g cm. A comparison with the previously calculated values for the case of a concentric shell will show that these power requirements for the four-pad system are only 26.5 percent as much as those for the concentric-shell case. It should be mentioned that these drag-torque and power-requirement values could be further re-

duced by using smaller pads ($\sigma < 60°$) and gases with a lower viscosity than air. For instance, in the case of hydrogen, the values are reduced to less than one-half those calculated for operation in air.

### Reference

[1] JPL Technical Report No. 32-1, Feb. 28, 1961; Laub, John H., and Norton, Robert H., Jr., *Externally Pressurized Spherical Gas Bearings*, ASLE Trans. 4, pp. 172–180, 1961.

✦ ✦ ✦

## Panels *(Continued from page 9)*

hence, secondary radiations are inimportant. Future space flights of much longer duration, however, will require thick shields. Then the secondary radiations arising from nuclear reactions are the most important.

The many processes and radiation interactions needed for predicting the effectiveness of thick shields are only poorly understood. Now is the time to emphasize the basic nuclear physics pertinent to this type of space shielding. The information so obtained will be vitally needed for planning manned missions to Mars and beyond.

Along with the research to improve the knowledge of shielding performance, there should be a considerable effort to understand better the sensitivity of the shielded item, living or not, to the imposed radiations. Shield attenuations to 10 percent are hardly required if the sensitivity of the shielded item to the radiations is uncertain to 100 percent.

Of course, radiations in the Van Allen belts and cosmic rays as well as the solar flares may contribute heavily to the dose of a crew if the exposure time is sufficiently long. Such might be the case for the crew of an orbiting space laboratory, or for a long-time mission leaving a low earth orbit via electric propulsion. For a two-week exposure time in the inner Van Allen belt with a 25 rem exposure limit, the shield weight would have to be 140 gm/sq cm (55 in. of water). Without shielding, the cosmic ray dose is about 0.65 rem per week, giving a manned trip-duration limit of about thirty-eight weeks.[3]

Radiations constitute only part of the environmental hazards that the space traveler might face. A great number of small bodies including comet material, zodiacal dust, and asteroidal material are orbiting the sun. These particles, generally called meteoroids, can have speeds relative to an earth launched spaceship from 11 to 73 km per second. Their densities range from 0.05 gm/cc for those of cometary origin to about 8.8 gm/cc for the nickel-iron meteorites. Most of the material is thought to be concentrated in the plane of the ecliptic and to be orbiting about the sun in the same direction as the earth. Fortunately, most of the particles are small, but even so, with their high speeds, they may penetrate spacecraft components and cause concern. The larger the spacecraft, the greater would be the probability for a penetration.

Reasonable estimates suggest that the tankage equivalent of an Atlas rocket in orbit would suffer a penetration once every 18 hours. Long duration space flights would thus require heavy shields to protect cabins, fuel and water storage tanks, and electric propulsion radiators.

Unfortunately penetration criteria for high-speed impact may be uncertain from one to three orders of magnitude. This uncertainty results partly from the limitations on penetration theory and partly because ground facilities can produce speeds comparable only to the slowest meteoroids. This situation suggests the desperate need for actual data on puncture rates in space.

The ill-fated Explorer XIII was an attempt to obtain such data. Unfortunately due to a poor orbit, the useful life of this satellite was less than three days.

The statistical nature of the problem suggests the need for meteoroid damage spacecraft with long useful lifetimes (6 mo to a year) and with many times the surface area of Explorer XIII exposed for penetration studies. Also needed is a comprehensive charting of the position, velocity, and momentum spectrum of the meteoroids in solar space. Hand in hand the ground experiments should continue—to provide design criteria for maximum meteoroid protection to the spacecraft with minimum weight sacrifices.

From such studies—both for meteoroid damage and for space radiation dangers, should come an understanding of the probability for man's survival in what could and may be a very hostile space environment.

### References

[1] Anderson, Kinsey A., *Prediction Aspects of Solar Proton Events*, Univ. of Calif. memo, July 1960.

[2] Fichtel, Carl E., *Discussion of Solar Proton Beams*, NASA — Goddard Space Flight Center, July 1960.

[3] Wallner, L. E., and Kaufman, H. R., *Radiation Shielding for Manned Space Flight*, NASA TN D-681, July 1961.

## Notice

Readers desiring information on English language translations of Soviet technical literature published in the U.S.—in addition to data published in AEROSPACE ENGINEERING, Vol. 20, No. 7, p. 42—may request it from the National Science Foundation or U.S. Department of Commerce, Office of Technical Services.

## Adventures (Continued from page 32)

matically controlled to meet the operating requirements of the rotary amplifier fields.

Each of the three rotary amplifiers supplies one phase of the main drive motor, together converting the voltage output of the power amplifiers to high current to drive the motor. We measured the angular velocity $W$ using a contact device. On the precision end of the centrifuge arm, we mounted a small flexible member which contacts a stationary member on the motor enclosure. Contact is made once every revolution and a pulse is generated at every contact. The pulse is shaped, amplified and fed into a counter which displays the time interval for that revolution. Using this time interval the angular velocity may readily be calculated.

The main bearing system of the machine consists of an upper, core-shaped member and an intermediate thrust bearing, both hydraulically operated. The upper bearing has a hydraulic pump for each of its three parts. The vertical component of hydraulic force tends to lift the machine off its seat for almost frictionless rotation. At the same time, the horizontal component centers the bearing in its journal.

The machine, a definite advance in design of precision centrifuge, has proved its value. As to the word "impossible," licking its implications is a sure-fire recipe for a real adventure in engineering.

✦

# Notice of Change

As authorized by the Council, and in conjunction with IAS Membership dues changes, the following basic subscription rate changes will be effective as of January 1, 1962.

AEROSPACE ENGINEERING: Annual, $10; single copy, $1.

JOURNAL OF THE AEROSPACE SCIENCES: Annual, $20; single copy, $2.

AE is received by IAS Graded Members as one of the benefits of membership; the *Journal* is available to these members for an additional $5 a year. There is no change in the *Journal* subscription rates to members, or to Student Members ($5 per year). AEROSPACE ENGINEERING rates to Student Members, however, had to be increased to $2.50 per year and have been in effect since September.

✦ ✦ ✦


## SHERMAN M. FAIRCHILD PUBLICATION FUND PAPERS

| No. | | Member | Nonmem. |
|---|---|---|---|
| FF-29 | Design Principles for a General Control Computer—R. Alonso and J. H. Laning, Jr. | $3.00 | $6.00 |
| FF-28 | Elementary Mechanics of Turbulent Fluid Motion—Max M. Munk | 2.00 | 4.00 |
| FF-27 | A Magnetic Support for Floated Inertial Instruments—P. J. Gilinson, Jr., W. G. Denhard, and R. H. Frazier | 2.00 | 4.00 |
| FF-26 | 2nd Supersonic Transport Proceedings—L. J. Lina, D. J. Maglieri, H. H. Hubbard, J. B. Pearson, Jr., R. J. Pfeiffer, B. C. Monesmith, R. A. Bailey, and R. H. Miller. | 1.50 | 3.00 |
| FF-23 | A Matrix Approach to Flutter Analysis—William P. Rodden. | 0.75 | 1.50 |
| FF-22 | Methods of Boundary-Layer Control for Postponing and Alleviating Buffeting and Other Effects of Shock-Induced Separation—H. H. Pearcey and C. M. Stuart. | 1.50 | 3.00 |
| FF-18 | On the Main Spray Generated by Planing Surfaces—Daniel Savitsky and John P. Breslin. | 0.75 | 1.25 |
| FF-17 | Atomic Reactors (a Symposium). | 1.25 | 1.75 |
| FF-14 | Engineering Management Philosophies (a Symposium). | 0.50 | 1.00 |
| FF-12 | Transonic Testing Techniques (a Symposium). | 1.85 | 2.50 |
| FF-10 | Improved Solutions of the Faulkner and Skan Boundary-Layer Equation—A. M. O. Smith. | 0.75 | 1.25 |
| FF-7 | Natural Flight and Related Aeronautics—James L. G. Fitz Patrick. | 2.65 | 3.50 |

| No. | | Member | Nonmem. |
|---|---|---|---|
| FF-4 | Finite Deflections of Curved Sandwich Plates and Sandwich Cylinders—F. K. Teichmann and Chi-Teh Wang. | $0.50 | $0.85 |
| FF-3 | The Penetration of a Fluid Surface by a Wedge—Experimental Towing Tank, Stevens Inst. of Tech. | 1.20 | 1.60 |
| 286 | Linearized Treatment of Supersonic Flow Through Axi-Symmetric Ducts with Prescribed Wall Contours—Charles E. Mack, Jr., and Ignace I. Kolodner. | 0.75 | 1.25 |
| 229 | Wave Profile of a Vee-Planing Surface, Including Test Data on a 30° Dead-Rise Surface—Experimental Towing Tank, Stevens Inst. of Tech. | 1.20 | 1.60 |
| 170 | Wave Contours in the Wake of a 10° Deadrise Planing Surface—Exp. Towing Tank, Stevens Inst. of Tech. | 1.20 | 1.60 |
| 168 | Wave Contours in the Wake of a 20° Deadrise Planing Surface—Exp. Towing Tank, Stevens Inst. Tech. | 1.20 | 1.60 |
| 167 | On the Pressure Distribution for a Wedge Penetrating a Fluid Surface—Experimental Towing Tank, Stevens Inst. of Tech. | 0.75 | 1.00 |
| 106 | Measurement of Ambient Air Temperature in Flight—W. Lavern Howland. | 0.35 | 0.50 |
| 104 | Tensor Analysis of Aircraft Structural Vibration—Charles E. Mack, Jr. | 1.85 | 2.50 |
| 102 | Electrical Resistance Strain Gages Applied to Wind-Tunnel Balances—Elmer C. Lundquist. | 0.60 | 0.80 |
| 101 | Introduction to Shock Wave Theory—J. G. Coffin. | 2.65 | 3.50 |
| 100 | Blade Pitching Moments of a Two-Bladed Rotor—R. W. Allen. | 0.75 | 1.00 |

***Order by number from:*** **Special Publications Dept., IAS, 2 E. 64th St., New York 21, N.Y.**

# Index to

# Aerospace Engineering, Volume 20

## January—December 1961

## Subject Index

(Author Index appears on page 86)


| | Month | Page |
|---|---|---|
| **Aerodynamics and Fluid Mechanics** | | |
| Aerodynamic Drag of Ground Effect Machines, Comments on, *Shigenori Ando* and *Jun-ichi Miyashita* | *Nov.* | 24 |
| An Aerodynamic-Influence-Coefficient Procedure, *William S. Johnson, Jr.*, and *George W. Martin* | *Sept.* | 22 |
| Application of Laminar Flow Control to Transport Aircraft, *Welko E. Gasich* | *Oct.* | 22 |
| Blunt-Nosed Slender Bodies, A Study of Flow Fields About Some Typical, *Roberto Vaglio-Laurin* and *Massimo Trella* | *Aug.* | 20 |
| Comments on Aerodynamic Drag of Ground Effect Machines, *Shigenori Ando* and *Jun-ichi Miyashita* | *Nov.* | 24 |
| Cruciform Wing Body Configurations at High Angles of Attack, Supersonic Induced Rolling-Moment Characteristics of, *J. F. Mello* and *K. R. Sivier* | *July* | 20 |
| Data Capsule Ejection Through a Re-Entry Body Wake, *Leonard C. MacAllister* and *Anthony M. Smith* | *May* | 8 |
| Design of Hypersonic Aircraft, *Hans Multhopp* | *Feb.* | 8 |
| Effects of Boundary Layer and Geometry on Characteristics of Perforated Walls for Transonic Wind Tunnels, *J. Lukasiewicz* | *Apr.* | 22 |
| Electrolysis of Water, Flow Visualization by, *Darwin W. Clutter* and *A. M. O. Smith* | *Jan.* | 24 |
| Flow Visualization by Electrolysis of Water, *Darwin W. Clutter* and *A. M. O. Smith* | *Jan.* | 24 |
| Flying Wind Tunnel, The Navy's, *Henry E. Payne III, Frank R. Carter,* and *Wayne J. Harrison* | *Mar.* | 18 |
| "Hydrofoils at the Crossroads," In the Wake of, *Various Contributors* | *May* | 28 |
| Hydrofoils at the Crossroads, *J. J. Stilwell, P. W. Nelson,* and *W. R. Porter* | *Mar.* | 10 |
| Hypersonic Aircraft, Design of, *Hans Multhopp* | *Feb.* | 8 |
| Hypersonic Flight, Optimization of Airfoils, *Coleman duP. Donaldson* and *K. Evan Gray* | *Jan.* | 18 |
| In the Wake of . . ."Hydrofoils at the Crossroads," *Various Contributors* | *May* | 28 |
| Inviscid Hypersonic Aerodynamics, Recent Soviet Advances in, *Ronald F. Probstein* | *July* | 10 |
| Laminar Flow Control to Transport Aircraft, Application of, *Welko E. Gasich* | *Oct.* | 22 |
| The Navy's Flying Wind Tunnel, *Henry E. Payne III, Frank R. Carter,* and *Wayne J. Harrison* | *Mar.* | 18 |
| Optimization of Airfoils for Hypersonic Flight, *Coleman duP. Donaldson* and *K. Evan Gray* | *Jan.* | 18 |
| Recent Soviet Advances in Inviscid Hypersonic Aerodynamics, *Ronald F. Probstein* | *July* | 10 |
| Re-Entry Body Wake, Data Capsule Ejection Through a, *Leonard C. MacAllister* and *Anthony M. Smith* | *May* | 8 |
| A Study of Flow Fields About Some Typical Blunt-Nosed Slender Bodies, *Roberto Vaglio-Laurin* and *Massimo Trella* | *Aug.* | 20 |
| Supersonic Induced Rolling-Moment Characteristics of Cruciform Wing Body Configurations at High Angles of Attack, *J. F. Mello* and *K. R. Sivier* | *July* | 20 |
| Transonic Wind Tunnels, Effects of Boundary Layer and Geometry on Characteristics of Perforated Walls for, *J. Lukasiewicz* | *Apr.* | 22 |
| **Aeroelasticity** | | |
| Aeroelasticity—It Still Poses Important Problems (Aerospace Technology as Seen by the Panels), *R. L. Bisplinghoff* | *Sept.* | 29 |
| **Communications** | | |
| Commercial Communications, Use of Satellites in, *Leonard Jaffe* | *Feb.* | 14 |
| Communication—Will the U. S. be First in Space? (Aerospace Technology as Seen by the Panels), *Peter C. Sandretto* | *Sept.* | 28 |
| Use of Satellites in Commercial Communications, *Leonard Jaffe* | *Feb.* | 14 |
| **Control and Guidance** | | |
| Agena Satellite Program, Some Experimental Results from the, *Ronald Smelt* and *Col. Frederic Oder* | *Feb.* | 10 |
| Control Considerations for a Lunar Soft Landing, *Arnold Peske* and *George Swanlund* | *Feb.* | 26 |
| Control of Ground Effect Machines—Preliminary Analysis, *David A. Lieberman, Peter G. Fielding,* and *William H. Neff* | *Dec.* | 28 |
| Directional Stability and Control With a Single Gyro, *Philip A. Henning* | *Sept.* | 20 |
| Flywheels, Satellite Attitude Stabilization by Means of, *William H. Stuart* | *Sept.* | 10 |
| Gas-Floated Spinning Spheres, *J. H. Laub* and *H. D. McGinness* | *Dec.* | 26 |
| Gyro Damping—Its Part in Platform Design, *E. M. Fischel* | *May* | 16 |
| Lunar Soft Landing, Control Considerations for a, *Arnold Peske* and *George Swanlund* | *Feb.* | 26 |
| Man-Machine Dynamics of Nose-Wheel Steering, *Joseph G. Wohl* | *Oct.* | 20 |
| Navigational Satellite System, Project Transit—Earth and Aerospace, *John D. Nicolaides* | *Feb.* | 20 |

| | Month | Page |
|---|---|---|
| A New Look at V/STOL Flying Qualities, *R. C. A'Harrah* and *S. F. Kwiatkowski* | *July* | 22 |
| Nose-Wheel Steering, Man-Machine Dynamics of, *Joseph G. Wohl* | *Oct.* | 20 |
| Parabolic Velocities, Piloted Simulation Studies of Re-Entry Guidance and Control at, *Rodney C. Wingrove* and *Robert E. Coate* | *Oct.* | 10 |
| Pilot Control of Rendezvous, *M. C. Kurbjun, R. F. Brissenden, E. C. Foudriat,* and *B. B. Burton* | *Mar.* | 20 |
| Piloted Simulation Studies of Re-Entry Guidance and Control at Parabolic Velocities, *Rodney C. Wingrove* and *Robert E. Coate* | *Oct.* | 10 |
| Platform Design, Gyro Damping—Its Part in, *E. M. Fischel* | *May* | 16 |
| Project Transit—Earth and Aerospace Navigational Satellite System, *John D. Nicolaides* | *Feb.* | 20 |
| Rendezvous, Pilot Control of, *M. C. Kurbjun, R. F. Brissenden, E. C. Foudriat,* and *B. B. Burton* | *Mar.* | 20 |
| Roll Requirements, Some Considerations of the Effects of Mission on, *W. M. Aubin* | *Sept.* | 16 |
| Satellite Attitude Stabilization by Means of Flywheels, *William H. Stuart* | *Sept.* | 10 |
| Single Gyro, Directional Stability and Control With a, *Philip A. Henning* | *Sept.* | 20 |
| Some Considerations of the Effects of Mission on Roll Requirements, *W. M. Aubin* | *Sept.* | 16 |
| Some Experimental Results From the Agena Satellite Program, *Ronald Smelt* and *Col. Frederic Oder* | *Feb.* | 10 |
| Temperature Sensitivity in Germanium Transistors (Adventures in Engineering), *James D. Mason* | *Oct.* | 27 |
| V/STOL Flying Qualities, A New Look at, *R. C. A'Harrah* and *S. F. Kwiatkowski* | *July* | 22 |

**Editorials**

| | | |
|---|---|---|
| The Forward Look— | *Apr.* | 9 |
| H. C. L. and Technical Societies | *Aug.* | 7 |
| In Memoriam—Edward Raymond Sharp, 1894–1961 | *Sept.* | 7 |
| The IAS Looks Ahead | *Mar.* | 9 |
| Leadership—the Priceless Ingredient | *Feb.* | 7 |
| The Next (X) Year—? | *Oct.* | 9 |
| The Pendulum Swings | *May* | 7 |
| The Scientist and His Responsibility | *July* | 7 |
| The State of Affairs | *Jan.* | 7 |
| This Is IAS | *June* | 9 |

**Energy Conversion**

| | | |
|---|---|---|
| Brittle Materials, Leading-Edge Design With, *Frank M. Anthony* and *Andrew L. Mistretta* | *Nov.* | 20 |
| Conversion of Heat to Electricity, Thermionic, *W. B. Nottingham, G. N. Hatsopoulos,* and *E. N. Carabateas* | *July* | 14 |
| Leading-Edge Design With Brittle Materials, *Frank M. Anthony* and *Andrew L. Mistretta* | *Nov.* | 20 |
| The Magnetic Particle Clutch—A Versatile Control Element for Rocket Systems, *Richard Grau* and *Bruce A. Chubb* | *Nov.* | 18 |
| Nuclear Energy in Space—Radioisotope Auxiliary Power Systems, *Jerome G. Morse* and *Douglas G. Harvey* | *Nov.* | 8 |
| Radioisotope Auxiliary Power Systems, Nuclear Energy in Space, *Jerome G. Morse* and *Douglas G. Harvey* | *Nov.* | 8 |
| Thermionic Conversion of Heat to Electricity, *W. B. Nottingham, G. N. Hatsopoulos,* and *E. N. Carabateas* | *July* | 14 |

**Flight Mechanics**

| | | |
|---|---|---|
| Approximations in Flight Optimization Problems, *John V. Breakwell* | *Sept.* | 26 |
| Flight Mechanics—Reliability—One of Today's Dominant Problems (Aerospace Technology as Seen by the Panels), *C. B. Westbrook* | *Oct.* | 25 |
| Flight Optimization Problems, Approximations in, *John V. Breakwell* | *Sept.* | 26 |
| Maneuverable Manned Vehicles, Supercircular Entry and Recovery With, *Robert H. Smith* and *Joseph A. Menard* | *Oct.* | 12 |
| Supercircular Entry and Recovery With Maneuverable Manned Vehicles, *Robert H. Smith* and *Joseph A. Menard* | *Oct.* | 12 |

**General Interest**

| | | |
|---|---|---|
| Aeronautical Scientists: How They Work and Where They Publish, Soviet, *Leon Trilling* | *July* | 12 |
| Analysis of Weapon Systems Effectiveness, *John G. Barmby* | *Jan.* | 14 |
| Finding Rare Documents (Adventures in Engineering), *Pearl I. Young* | *Nov.* | 26 |
| Soviet Aeronautical Scientists: How They Work and Where They Publish, *Leon Trilling* | *July* | 12 |
| Twenty Times Better—The Story of the Building of a Centrifuge (Adventures in Engineering), *Harry Weitz* | *Dec.* | 32 |
| Weapon Systems Effectiveness, Analysis, *John G. Barmby* | *Jan.* | 14 |
| We Have the Responsibility to Communicate, *Daniel O. Dommasch* | *May* | 12 |

**Instrumentation**

| | | |
|---|---|---|
| Compliance of Nonuniform Gimbals, *Ira Cochin* | *Apr.* | 24 |
| Early Blind Flying, *J. H. Doolittle* | *Oct.* | 14 |
| Economics of Instrumentation Precision for Space Vehicle Development, *V. R. Boulton* | *Mar.* | 30 |
| History's Most Elusive Paper Cup (Adventures in Engineering), *George Blackburne* | *Sept.* | 31 |
| Instrumentation Precision for Space Vehicle Development, Economics of, *V. R. Boulton* | *Mar.* | 30 |
| Nonuniform Gimbals, Compliance of, *Ira Cochin* | *Apr.* | 24 |
| Space Man vs. Space Machine, *A. R. Hibbs* | *Apr.* | 20 |

**Management**

| | | |
|---|---|---|
| For the Air Force—A New Scientific Management Technique, *Lee A. Ohlinger* | *Nov.* | 10 |
| Management—Relating Industrial Research to Company Goals (Aerospace Technology as Seen by the Panels), *Lewis A. Robert* | *Oct.* | 26 |

**Meteorology**

| | | |
|---|---|---|
| Atmosphere Soundings, Optical Tracers for, *Edward R. Manring* | *Sept.* | 8 |
| High-Altitude Wind Observations Above Cape Canaveral, *J. W. Smith* and *W. W. Vaughan* | *Oct.* | 16 |

| | Month | Page |
|---|---|---|
| Meteorological Satellite Systems in Weather Research and Services, *F. W. Reichelderfer* | *Mar.* | 22 |
| Optical Tracers for Atmosphere Soundings, *Edward R. Manring* | *Sept.* | 8 |
| Weather Research and Services, Meteorological Satellite Systems in, *F. W. Reichelderfer* | *Mar.* | 22 |
| Weather—Take It or Make It, *Luis de Florez* | *Sept.* | 24 |

**Nuclear Applications**

| | | |
|---|---|---|
| Aerospace Nuclear Power Safety Considerations, *Lt. Col. Joseph A. Connor, Jr.* | *May* | 26 |
| A Conceptual Nuclear Propulsion System for Ground Effect Machines, *J. C. Westmoreland, J. B. Dee,* and *J. E. Loos* | *July* | 16 |
| Cosmic Rays, Nuclear Reactors, and Manned Space Systems, *David Reitz* | *Apr.* | 28 |
| Ground Effect Machines, A Conceptual Nuclear Propulsion System for, *J. C. Westmoreland, J. B. Dee,* and *J. E. Loos* | *July* | 16 |
| Manned Nuclear-Rocket Missions to Mars, A Study of, *S. C. Himmel, J. F. Dugan, Jr., R. W. Luidens,* and *R. J. Weber* | *July* | 18 |
| Nuclear Electric Power for Space Missions, *Terry W. Koerner* and *John J. Paulson* | *May* | 18 |
| Nuclear Energy in Space—Radioisotope Auxiliary Power Systems, *J. G. Morse* and *D. G. Harvey* | *Nov.* | 8 |
| Nuclear Propulsion System for Ground Effect Machines, A Conceptual, *J. C. Westmoreland, J. B. Dee,* and *J. E. Loos* | *July* | 16 |
| Nuclear Reactors, and Manned Space Systems, Cosmic Rays, *David Reitz* | *Apr.* | 28 |
| Nuclear Rocket Stages Increase Saturn's Payload Capability, *Willis Y. Jordan, Jr., Donald R. Saxton,* and *Paul G. Thomas* | *May* | 14 |
| Radioisotope Auxiliary Power Systems, Nuclear Energy in Space, *Jerome G. Morse* and *Douglas G. Harvey* | *Nov.* | 8 |
| Saturn's Payload Capability, Nuclear Rocket Stages Increase, *Willis Y. Jordan, Jr., Donald R. Saxton,* and *Paul G. Thomas* | *May* | 14 |
| Space Missions, Nuclear Electric Power for, *Terry W. Koerner* and *John J. Paulson* | *May* | 18 |
| A Study of Manned Nuclear-Rocket Missions to Mars, *S. C. Himmel, J. F. Dugan, Jr., R. W. Luidens,* and *R. J. Weber* | *July* | 18 |

**Operations**

| | | |
|---|---|---|
| Air Transportation, Short-Haul, *William P. Kennedy* | *Dec.* | 24 |
| Aircraft Dynamic Response in Real-Time by a Digital Computer System, Reproduction of, *Henry J. Wychorski* | *May* | 10 |
| Aircraft Launching and Recovery Systems: Recent Advances and Their Potential Application to Commercial Aircraft—Part I, *Capt. William C. Fortune* | *Apr.* | 12 |
| Aircraft Launching and Recovery Systems: Recent Advances and Their Potential Application to Commercial Aircraft—Part II, *Capt. William C. Fortune* | *May* | 24 |
| Antisubmarine Warfare, Problems of, *John E. Clark* | *Dec.* | 14 |
| Application of Laminar Flow Control to Transport Aircraft, *Welko E. Gasich* | *Oct.* | 22 |
| Astronautics, Soviet Space Experiments and, *F. J. Krieger* | *July* | 8 |
| Boosters—Analysis of Their Potentialities, Recoverable Air-Breathing, *C. W. Frick* and *T. Strand* | *Feb.* | 22 |
| Commercial Aircraft—Part I, Aircraft Launching and Recovery Systems: Recent Advances and Their Potential Application to, *Capt. William C. Fortune* | *Apr.* | 12 |
| Part II | *May* | 24 |
| The Fleet Carrier Attack Problem in Limited War, *George R. Gehrkens* | *Dec.* | 12 |
| Future Anti-Air Warfare—The Missile Threat, *W. Paul Thayer* | *Dec.* | 16 |
| Laminar Flow Control to Transport Aircraft, Application of, *Welko E. Gasich* | *Oct.* | 22 |
| Naval Attack Aviation for Limited War, 1965–1975, *Richard Hutton* | *Dec.* | 10 |
| Navy/Industry Look at the Future, A Political Economist Views the, *Oskar Morgenstern* | *Dec.* | 22 |
| One-Shot Mission Success at Minimum Cost, *W. E. Cox* and *W. W. Harter* | *Nov.* | 22 |
| Operations—V/STOL Worries Lie Ahead (Aerospace Technology as Seen by the Panels), *Benjamin S. Kelsey* | *Sept.* | 30 |
| A Political Economist Views the Navy/Industry Look at the Future, *Oskar Morgenstern* | *Dec.* | 22 |
| Problems of Antisubmarine Warfare, *John E. Clark* | *Dec.* | 14 |
| Rapid Sea-Wide Supply, *Donald W. Douglas, Jr.* | *Dec.* | 18 |
| Recoverable Air-Breathing Boosters—Analysis of Their Potentialities, *C. W. Frick* and *T. Strand* | *Feb.* | 22 |
| Recovery Systems: Recent Advances and Their Potential Application to Commercial Aircraft—Part I, Aircraft Launching and, *Capt. William C. Fortune* | *Apr.* | 12 |
| Part II | *May* | 24 |
| Reproduction of Aircraft Dynamic Response in Real-Time by a Digital Computer System, *Henry J. Wychorski* | *May* | 10 |
| Research Management?, Whither Aerospace Industry, *Lewis A. Rodert* | *Mar.* | 24 |
| The RIAS Enterprise, *Welcome W. Bender* | *Feb.* | 28 |
| Short-Haul Air Transportation, *William P. Kennedy* | *Dec.* | 24 |
| Space Experiments and Astronautics, Soviet, *F. J. Krieger* | *June* | 8 |
| Whither Aerospace Industry Research Management?, *Lewis A. Rodert* | *Mar.* | 24 |

**Propulsion Systems**

| | | |
|---|---|---|
| A Conceptual Nuclear Propulsion System for Ground Effect Machines, *J. C. Westmoreland, J. B. Dee,* and *J. E. Loos* | *July* | 16 |
| Base Flow Characteristics of Missiles With Cluster-Rocket Exhausts, *B. H. Goethert* | *Mar.* | 28 |
| Experimental Designs for Rocket Motors, *Norman R. Garner, D. E. Hartvigsen,* and *Richard W. Vail, Jr.* | *Mar.* | 12 |
| Free Turbine Systems in Rotary Wing Aircraft, *Henry F. Hrubecky* | *Jan.* | 10 |
| Ground Effect Machines, A Conceptual Nuclear Propulsion System for, *J. C. Westmoreland, J. B. Dee,* and *J. E. Loos* | *July* | 16 |
| Jet Aircraft—Selection and Design, Thrust Reversers for, *John C. Pickerd* | *Jan.* | 30 |
| Laminar Flow Aircraft, Propulsion Systems for, *J. W. Connors, W. Pfenninger,* and *C. B. Smith* | *Aug.* | 16 |
| Manned Nuclear-Rocket Missions to Mars, A Study of, *S. C. Himmel, J. F. Dugan, Jr., R. W. Luidens,* and *R. J. Weber* | *July* | 18 |
| Missiles With Cluster-Rocket Exhaust, Base Flow Characteristics of, *B. H. Goethert* | *Mar.* | 28 |
| A New Type of Thermal Radiator for Space Vehicles, *Roger C. Weatherston* and *William E. Smith* | *Jan.* | 16 |

| | Month | Page |
|---|---|---|
| Nuclear Propulsion System for Ground Effect Machines, A Conceptual, *J. C. Westmoreland, J. B. Dee*, and *J. E. Loos* | *July* | 16 |
| Propellant Specific Impulse and Density, Trade-Off Between, *Leonard J. Gordon* | *Nov.* | 12 |
| Propulsion Requirements, Supersonic Transport Propulsion, *Mark R. Nichols* | *Sept.* | 12 |
| Propulsion Systems for Laminar Flow Aircraft, *J. W. Connors, W. Pfenninger*, and *C. B. Smith* | *Aug.* | 16 |
| Rocket Motors, Experimental Designs for, *Norman R. Ganner, D. E. Harvigsen*, and *Richard W. Vail, Jr.* | *Mar.* | 12 |
| Rotary Wing Aircraft, Free Turbine Systems in, *Henry F. Hrubecky* | *Jan.* | 10 |
| Space Vehicles, A New Type of Thermal Radiator for, *Roger C. Weatherston* and *William E. Smith* | *Jan.* | 16 |
| A Study of Manned Nuclear-Rocket Missions to Mars, *S. C. Himmel, J. F. Dugan, Jr., R. W. Luidens*, and *R. J. Weber* | *July* | 18 |
| Supersonic Transport Propulsion Requirements, *Mark R. Nichols* | *Sept.* | 12 |
| Thermal Radiator for Space Vehicles, A New Type of, *Roger C. Weatherston* and *William E. Smith* | *Jan.* | 16 |
| Thrust Reversers for Jet Aircraft—Selection and Design, *John C. Pickerd* | *Jan.* | 30 |
| Trade-Off Between Propellant Specific Impulse and Density, *Leonard J. Gordon* | *Nov.* | 12 |

**Space Physics**

| | | |
|---|---|---|
| Approximating Technique for Variational Problems, *Lu Ting* | *Jan.* | 32 |
| The Hodograph and Ballistic Missile Trajectory Problems, *Erwin W. Paul* | *Feb.* | 24 |
| Injection Schemes for Obtaining a Twenty-Four Hour Orbit, *Rudolf F. Hoelker* and *Robert Silber* | *Jan.* | 28 |
| Manned Space Flight, Space Physics: Environment for (Aerospace Technology as Seen by the Panels), *John C. Evvard* | *Dec.* | 9 |
| Natural Satellites of the Earth, Tektites and, *John A. O'Keefe* and *Barbara E. Shute* | *July* | 26 |
| Space Physics: Environment for Manned Space Flight (Aerospace Technology as Seen by the Panels), *John C. Evvard* | *Dec.* | 9 |
| Tektites and Natural Satellites of the Earth, *John A. O'Keefe* and *Barbara E. Shute* | *July* | 26 |
| Trajectory Problems, The Hodograph and Ballistic Missile, *Erwin W. Paul* | *Feb.* | 24 |
| Twenty-Four Hour Orbit, Injection Schemes for Obtaining a, *Rudolf F. Hoelker* and *Robert Silber* | *Jan.* | 28 |
| Variational Problems, Approximating Technique for, *Lu Ting* | *Jan.* | 32 |

**Structures and Materials**

| | | |
|---|---|---|
| All-Welded Tubular Truss Core Sandwich, Development of, *Bertram Klein* | *May* | 22 |
| Ballistic Missiles and Space Vehicles, Sandwich Construction for Primary Structure of, *Ralph F. Foral* | *July* | 24 |
| Biaxial Stress Problems in Fabric Structures, An Introduction to, *A. D. Topping* | *Apr.* | 18 |
| Cross Method, Thermal-Stress Analysis of Sandwich-Type Cylindrical Shells by the, *John C. Yao* | *Aug.* | 24 |
| Design Implications of Creep in Pressurized Cylindrical Shells, *Ivan Rattinger* and *Joseph Padlog* | *Mar.* | 26 |
| Development of an All-Welded Tubular Truss Core Sandwich, *Bertram Klein* | *May* | 22 |
| Ductile Materials, Tensile Instability (Necking) of, *F. R. Shanley* | *Dec.* | 30 |
| Effect of Forming and Welding on Stainless Steel Columns, *Robert E. Petersen* and *Axel O. Bergholm* | *Apr.* | 26 |
| High Stress Level Fatigue, A Unified Engineering Theory of, *Sitaram Rao Valluri* | *Oct.* | 18 |
| Hypersonic Re-Entry Glide Vehicle, Modes of Failure of a, *Jerome E. Fischler* | *Sept.* | 14 |
| Hyperthermal Gas-Fueled Materials Test Facility, *M. John Brown* | *Aug.* | 18 |
| An Introduction to Biaxial Stress Problems in Fabric Structures, *A. D. Topping* | *Apr.* | 18 |
| Mechanisms of Surface Removal From Metals in Space, *John L. Ham* | *May* | 20 |
| Metals in Space, Mechanisms of Surface Removal From, *John L. Ham* | *May* | 20 |
| Modes of Failure of a Hypersonic Re-Entry Glide Vehicle, *Jerome E. Fischler* | *Sept.* | 14 |
| On the Development of Low-Cost, Formable, All-Metal Sandwich Panels With Corrugated Cores, *Mortimer J. Lowy* and *Robert I. Jaffee* | *Nov.* | 14 |
| Tensile Instability (Necking) of Ductile Materials, *F. R. Shanley* | *Dec.* | 30 |
| Pressurized Cylindrical Shells, Design Implications of Creep in, *Ivan Rattinger* and *Joseph Padlog* | *Mar.* | 26 |
| Response of Plates to Moving Shocks, *Eric E. Ungar* | *Mar.* | 16 |
| Sandwich Construction for Primary Structure of Ballistic Missiles and Space Vehicles, *Ralph F. Foral* | *July* | 24 |
| Sandwich Panels With Corrugated Cores, On the Development of Low-Cost, Formable, All-Metal, *Mortimer J. Lowy* and *Robert I. Jaffee* | *Nov.* | 14 |
| Sandwich-Type Cylindrical Shells by the Cross Method, Thermal-Stress Analysis of, *John C. Yao* | *Aug.* | 24 |
| Shocks, Response of Plates to Moving, *Eric E. Ungar* | *Mar.* | 16 |
| Space Vehicles, Sandwich Construction for Primary Structure of Ballistic Missiles and, *Ralph F. Foral* | *July* | 24 |
| Stainless Steel Column, Effect of Forming and Welding on, *Robert E. Petersen* and *Axel O. Bergholm* | *Apr.* | 26 |
| Test Facility, Hyperthermal Gas-Fueled Materials, *M. John Brown* | *Aug.* | 18 |
| A Unified Engineering Theory of High Stress Level Fatigue, *Sitaram Rao Valluri* | *Oct.* | 18 |

**Support**

| | | |
|---|---|---|
| Aircraft Support Equipment at Sea, *Leonard Lipson* and *Thomas A. Lyle* | *June* | 18 |
| Application of Operations Research for Site Planning Facilities Support, *Phillip J. Daniel* | *June* | 26 |
| Automatic In-Flight Evaluation, Support of Fire Control Reliability by, *Stuart T. Belden* | *June* | 30 |
| Central Management, Networks of Decentralized Decisions Under, *R. W. Bragg* and *Edward B. Hincks* | *June* | 14 |
| Compatibility of Freon 114 Used in Mercury Support Equipment With Various Hose Materials, *W. C. Stormer* | *June* | 28 |
| Corrosion Problems Encountered in Silo Storage of Missiles, *Leo E. Gatzek* | *June* | 34 |
| Design of Space Power Systems, Environmental Problems in the, *M. A. Zipkin* | *Aug.* | 14 |

| | Month | Page |
|---|---|---|
| Electromechanical Field Maintenance Equipment, Hawk Hydraulic and, *Theodore Jacobsohn* and *Henry A. Matarazzo* | *June* | 36 |
| Electronic Repair Shops, Hawk Missile System, *W. J. Perreault* | *June* | 16 |
| Environmental Problems in the Design of Space Power Systems, *M. A. Zipkin* | *Aug.* | 14 |
| Equipment at Sea, Aircraft Support, *Leonard Lipson* and *Thomas A. Lyle* | *June* | 18 |
| The First Titan Hardened Facilities, *Marvin J. Kudroff* | *June* | 10 |
| Freon 114 Used in Mercury Support Equipment With Various Hose Materials, Compatibility, of, *W. C. Stormer* | *June* | 28 |
| Hawk Hydraulic and Electromechanical Field Maintenance Equipment, *Theodore Jacobsohn* and *Henry A. Matarazzo* | *June* | 36 |
| Hawk Missile System Electronic Repair Shops, *W. J. Perreault* | *June* | 16 |
| Lunar Support Equipment—The Time Is Now, Support—(Aerospace Technology as Seen by the Panels), *Gilbert Rolan* | *Dec.* | 8 |
| The Mini-Recorder System, *J. B. Renfro* | *June* | 32 |
| Minuteman Missile Transportation System, *George T. Drakeley* | *June* | 22 |
| Missile Ranges in Support of Space, The Role of the National, *Paul T. Cooper* | *Sept.* | 18 |
| Networks of Decentralized Decisions Under Central Management, *R. W. Bragg* and *Edward B. Hincks* | *June* | 14 |
| Operation Non-Routine: Maintenance Support Trends of Subsonic and Supersonic Transports, *P. A. Hartline* | *June* | 38 |
| Parabolic Velocities, Piloted Simulation Studies of Re-Entry Guidance and Control at, *Rodney C. Wingrove* and *Robert E. Coate* | *Oct.* | 10 |
| Piloted Simulation Studies of Re-Entry Guidance and Control at Parabolic Velocities, *Rodney C. Wingrove* and *Robert E. Coate* | *Oct.* | 10 |
| Range Safety—A Necessary Evil, *Adolf H. Knothe* | *June* | 20 |
| Rapid Sea-Wide Supply, *Donald W. Douglas, Jr.* | *Dec.* | 18 |
| Rocket Vehicles, Vertical Floating Launch of, *Lt. Comdrs. J. E. Draim* and *C. E. Stalzer* | *June* | 12 |
| The Role of the National Missile Ranges in Support of Space Operations, *Paul T. Cooper* | *Sept.* | 18 |
| Silo Storage of Missiles, Corrosion Problems Encountered in, *Leo E. Gatzek* | *June* | 34 |
| Site Planning Facilities Support, Application of Operation Research for, *Phillip J. Daniel* | *June* | 26 |
| Space and Democracy, *Richard S. Morse* | *June* | 24 |
| Subsonic and Supersonic Transports, Operation Non-Routine: Maintenance Support Trends of, *P. A. Hartline* | *June* | 38 |
| Support—Lunar Support Equipment—The Time Is Now (Aerospace Technology as Seen by the Panels), *Gilbert Rolan* | *Dec.* | 8 |
| Support—Problems in Concurrent Development and Production (Aerospace Technology as Seen by the Panel), *William R. Owens* | *Nov.* | 6 |
| Support of Fire Control Reliability by Automatic In-Flight Evaluation, *Stuart T. Belden* | *June* | 30 |
| Titan Hardened Facilities, The First, *Marvin J. Kudroff* | *June* | 10 |
| Transportation System, Minuteman Missile, *George T. Drakeley* | *June* | 22 |
| Vertical Floating Launch of Rocket Vehicles, *Lt. Comdrs. J. E. Draim* and *C. E. Stalzer* | *June* | 12 |
| X-15 Flight Simulation Program, *Norman R. Cooper* | *Nov.* | 16 |


## Vehicle Design


| | Month | Page |
|---|---|---|
| Airborne With the Curtiss A-1 Replica, *D. P. Germeraad* | *Dec.* | 20 |
| The Application of Impulsive Excitation to In-Flight Vibration Testing, *Vaughn L. Beals and Stanley R. Hurley* | *Jan.* | 8 |
| An Approach to Operational Features Desirable in a Militarily Acceptable GEM, *Peter G. Fielding* | *Feb.* | 18 |
| Cargo Airplane Characteristics, V/STOL, *W. C. J. Garrard* | *Jan.* | 22 |
| A Conceptual Nuclear Propulsion System for Ground Effect Machines, *J. C. Westmoreland, J. B. Dee,* and *J. E. Loos* | *July* | 16 |
| Design of Hypersonic Aircraft, *Hans Multhopp* | *Feb.* | 8 |
| Design Problems, Hovercraft—Some, *R. Stanton Jones* | *Feb.* | 16 |
| Dyna-Soar: A Review of the Technology, *Yusuf A. Yoler* | *Aug.* | 8 |
| Ejectable-Nose Escape Capsule, Supersonic, *Mell D. Cassidy* and *Philip J. Sullivan* | *Mar.* | 14 |
| GEM's, Performance of Nomograms for, *Peter G. Fielding* | *Aug.* | 10 |
| Ground Effect Machines, A Conceptual Nuclear Propulsion System for, *J. C. Westmoreland, J. B. Dee,* and *J. E. Loos* | *July* | 16 |
| Hovercraft—Some Design Problems, *R. Stanton Jones* | *Feb.* | 16 |
| Hypersonic Aircraft, Design of, *Hans Multhopp* | *Feb.* | 8 |
| The Inflated Satellite: Characteristics in Sunlight and Darkness, *Herman Mark* and *Simon Ostrach* | *Apr.* | 10 |
| The Interdependence of Manned Spacecraft Design and Radiation Shielding, *L. J. Barbieri* and *S. Lampert* | *Apr.* | 14 |
| Lifting Fan Design Selection and Performance, V/STOL Logistic Transport, *Elliot Kazan* and *Wilbur Bergen* | *Apr.* | 16 |
| Manned Spacecraft Design and Radiation Shielding, The Interdependence of, *L. J. Barbieri* and *S. Lampert* | *Apr.* | 14 |
| Nuclear Propulsion System for Ground Effect Machines, A Conceptual, *J. C. Westmoreland, J. B. Dee,* and *J. E. Loos* | *July* | 16 |
| Operational Features Desirable in a Militarily Acceptable GEM, An Approach to, *Peter G. Fielding* | *Feb.* | 18 |
| Performance of Nomograms for GEM's, *Peter G. Fielding* | *Aug.* | 10 |
| Radiation Shielding, The Interdependence of Manned Spacecraft Design, *L. J. Barbieri* and *S. Lampert* | *Apr.* | 14 |
| Rapid Sea-Wide Supply, *Donald W. Douglas, Jr.* | *Dec.* | 18 |
| Satellite: Characteristics in Sunlight and Darkness, The Inflated, *Herman Mark* and *Simon Ostrach* | *Apr.* | 10 |
| Supersonic Ejectable-Nose Escape Capsule, *Mell D. Cassidy* and *Phillip J. Sullivan* | *Mar.* | 14 |
| Vehicle Design—Some Notes on Aerospace Vehicle Design Trends (Aerospace Technology as Seen by the Panels), *Adolph Burstein* | *Oct.* | 24 |
| Vehicle Design—A Survey of Vehicle Design Problems (Aerospace Technology as Seen by the Panels), *C. E. Pappas* | *Nov.* | 7 |
| Vibration Testing, The Application of Impulsive Excitation to In-Flight, *Vaughn L. Beals* and *Stanley R. Hurley* | *Jan.* | 8 |

| | Month | Page |
|---|---|---|
| V/STOL Aircraft Flight Test Experience, XV-3 Low-Disc-Loading, *C. E. Davis* and *R. L. Lichten* | *Aug.* | 22 |
| V/STOL Cargo Airplane Characteristics, *W. C. J. Garrard* | *Jan.* | 22 |
| V/STOL Logistic Transport: Lifting Fan Design Selection and Performance, *Elliot Kazan* and *Wilbur Bergen* | *Apr.* | 16 |
| The X-15, *George R. Mellinger* | *Aug.* | 12 |
| XV-3 Low-Disc-Loading V/STOL Aircraft Flight Test Experience, *C. E. Davis*, and *R. L. Lichten* | *Aug.* | 22 |
| X-15, The, *George R. Mellinger* | *Aug.* | 12 |


# Author Index


| | Month | Page |
|---|---|---|
| A'HARRAH, R. C., AND S. F. KWIATKOWSKI. A New Look at V/STOL Flying Qualities | *July* | 22 |
| ANDO, SHIGENORI, AND JUN-ICHI MIYASHITA. Comments on Aerodynamic Drag of Ground Effect Machines | *Nov.* | 24 |
| ANTHONY, FRANK M., AND ANDREW L. MISTRETTA. Leading-Edge Design With Brittle Materials | *Nov.* | 20 |
| AUBIN, W. M. Some Considerations of the Effects of Mission on Roll Requirements | *Sept.* | 16 |
| BARBIERI, L. J., AND S. LAMPERT. The Interdependence of Manned Spacecraft Design and Radiation Shielding | *Apr.* | 14 |
| BARMBY, JOHN G. Analysis of Weapon Systems Effectiveness | *Jan.* | 14 |
| BEALS, VAUGHN L., AND STANLEY R. HURLEY. The Application of Impulsive Excitation to In-Flight Vibration Testing | *Jan.* | 8 |
| BELDEN, STUART T. Support of Fire Control Reliability by Automatic In-Flight Evaluation. | *June* | 30 |
| BENDER, WELCOME W. The RIAS Enterprise | *Feb.* | 28 |
| BERGEN, WILBUR, AND ELLIOT KAZAN. V/STOL Logistic Transport: Lifting Fan Design Selection and Performance | *Apr.* | 16 |
| BERGHOLM, AXEL O., AND ROBERT E. PETERSEN. Effect of Forming and Welding on Stainless Steel Columns | *Apr.* | 26 |
| BISPLINGHOFF, R. L. Aeroelasticity—It Still Poses Important Problems (Aerospace Technology as Seen by the Panels) | *Sept.* | 29 |
| BLACKBURN, GEORGE. History's Most Elusive Paper Cup (Adventures in Engineering) | *Sept.* | 31 |
| BOULTON, V. R. Economics of Instrumentation Precision for Space Vehicle Development | *Mar.* | 30 |
| BRAGG, R. W., AND EDWARD B. HINCKS. Networks of Decentralized Decisions Under Central Management | *June* | 14 |
| BREAKWELL, JOHN V. Approximations in Flight Optimization Problems | *Sept.* | 26 |
| BRISSENDEN, R. F., M. C. KURBJUN, E. C. FOUDRIAT, AND B. B. BURTON. Pilot Control of Rendezvous | *Mar.* | 20 |
| BROWN, JOHN M. Hyperthermal Gas-Fueled Materials Test Facility | *Aug.* | 18 |
| BURSTEIN, ADOLPH. Vehicle Design—Some Notes on Aerospace Vehicle Design Trends (Aerospace Technology as Seen by the Panels) | *Oct.* | 24 |
| BURTON, B. B., M. C. KURBJUN, R. F. BRISSENDEN, AND E. C. FOUDRIAT. Pilot Control of Rendezvous | *Mar.* | 20 |
| CARABATEAS, E. N., W. B. NOTTINGHAM, AND G. N. HATSOPOULOS. Thermionic Conversion of Heat to Electricity | *July* | 14 |
| CARTER, FRANK R., HENRY E. PAYNE, III, AND WAYNE J. HARRISON. The Navy's Flying Wind Tunnel | *Mar.* | 18 |
| CASSIDY, MELL D., AND PHILLIP J. SULLIVAN. Supersonic Ejectable-Nose Escape Capsule | *Mar.* | 14 |
| CHUBB, BRUCE A., AND RICHARD GRAU. The Magnetic Particle Clutch—A Versatile Control Element for Rocket Systems | *Nov.* | 18 |
| CLARK, JOHN E. Problems of Antisubmarine Warfare | *Dec.* | 14 |
| CLUTTER, DARWIN W., AND A. M. O. SMITH. Flow Visualization by Electrolysis of Water | *Jan.* | 24 |
| COATE, ROBERT E., AND RODNEY C. WINGROVE. Piloted Simulation Studies of Re-Entry Guidance and Control at Parabolic Velocities | *Oct.* | 10 |
| COCHIN, IRA. Compliance of Nonuniform Gimbals | *Apr.* | 24 |
| CONNOR, LT. COL. JOSEPH A., JR. Aerospace Nuclear Power Safety Considerations | *May* | 26 |
| CONNORS, J. W., W. PFENNINGER, AND C. B. SMITH. Propulsion Systems for Laminar Flow Aircraft | *Aug.* | 16 |
| COOPER, NORMAN R. X-15 Flight Simulation Program | *Nov.* | 16 |
| COOPER, PAUL T. The Role of the National Missile Ranges in Support of Space Operations | *Sept.* | 18 |
| COX, W. E., AND W. W. HARTER. One-Shot Mission Success at Minimum Cost | *Nov.* | 22 |
| DANIEL, PHILLIP J. Application of Operations Research for Site Planning Facilities Support | *June* | 26 |
| DAVIS, C. E., AND R. L. LICHTEN. XV-3 Low-Disc-Loading V/STOL Aircraft Flight Test Experience | *Aug.* | 22 |
| DEE, J. B., J. C. WESTMORELAND, AND J. E. LOOS. A Conceptual Nuclear Propulsion System for Ground Effect Machines | *July* | 16 |
| DOMMASCH, DANIEL O. We Have the Responsibility to Communicate | *May* | 12 |
| DONALDSON, COLEMAN DUP., AND K. EVAN GRAY. Optimization of Airfoils for Hypersonic Flight | *Jan.* | 18 |
| DOOLITTLE, J. H. Early Blind Flying | *Oct.* | 14 |
| DOUGLAS, DONALD W., JR. Rapid Sea-Wide Supply | *Dec.* | 18 |
| DRAIM, J. E., AND C. E. STALZER, LT. COMDRS. Vertical Floating Launch of Rocket Vehicles | *June* | 12 |
| DRAKELEY, GEORGE T. Minuteman Missile Transportation System | *June* | 22 |
| DUGAN, J. F., JR., S. C. HIMMEL, R. W. LUIDENS, AND R. J. WEBER. A Study of Manned Nuclear-Rocket Missions to Mars | *July* | 18 |
| EVVARD, JOHN C. Space Physics: Environment for Manned Space Flight (Aerospace Technology as Seen by the Panels) | *Dec.* | 9 |
| FIELDING, PETER G. Performance of Nomograms for GEM's | *Aug.* | 10 |

| | Month | Page |
|---|---|---|
| FIELDING, PETER G. An Approach to Operational Features Desirable in a Militarily Acceptable GEM | *Feb.* | 18 |
| FIELDING, PETER G., DAVID A. LIEBERMAN, AND WILLIAM H. NEFF. Control of Ground Effect Machines—Preliminary Analysis | *Dec.* | 28 |
| FISCHEL, E. M. Gyro Damping—Its Part in Platform Design | *May* | 16 |
| FISCHLER, JEROME E. Modes of Failure of a Hypersonic Re-Entry Glide Vehicle | *Sept.* | 14 |
| FLOREZ, LUIS DE. Weather—Take It or Make It | *Sept.* | 24 |
| FORAL, RALPH F. Sandwich Construction for Primary Structure of Ballistic Missiles and Space Vehicles | *July* | 24 |
| FORTUNE, CAPT. WILLIAM C. Aircraft Launching and Recovery Systems—Recent Advances and Their Potential Application to Commercial Aircraft—Part I | *Apr.* | 12 |
| Part II | *May* | 24 |
| FOUDRIAT, E. C., M. C. KURBJUN, R. F. BRISSENDEN, AND B. B. BURTON. Pilot Control of Rendezvous | *Mar.* | 20 |
| FRICK, C. W., AND T. STRAND. Recoverable Air-Breathing Boosters—Analysis of Their Potentialities | *Feb.* | 22 |
| GARNER, NORMAN R., D. E. HARTVIGSEN, AND RICHARD W. VAIL, JR. Experimental Designs for Rocket Motors | *Mar.* | 12 |
| GARRARD, W. C. J. V/STOL Cargo Airplane Characteristics | *Jan.* | 22 |
| GASICH, WELKO E. Application of Laminar Flow Control to Transport Aircraft | *Oct.* | 22 |
| GATZEK, LEO E. Corrosion Problems Encountered in Silo Storage of Missiles | *June* | 34 |
| GEHRKENS, GEORGE R. The Fleet Carrier Attack Problem in Limited War | *Dec.* | 12 |
| GERMERAAD, D. P. Airborne With the Curtiss A-1 Replica | *Dec.* | 20 |
| GOETHERT, B. H. Base Flow Characteristics of Missiles With Cluster-Rocket Exhausts | *Mar.* | 28 |
| GORDON, LEONARD J. Trade-Off Between Propellant Specific Impulse and Density | *Nov.* | 12 |
| GRAU, RICHARD, AND BRUCE A. CHUBB. The Magnetic Particle Clutch—A Versatile Control Element for Rocket Systems | *Nov.* | 18 |
| GRAY, K. EVAN, AND COLEMAN DUP. DONALDSON. Optimization of Airfoils for Hypersonic Flight | *Jan.* | 18 |
| HAM, JOHN L. Mechanisms of Surface Removal From Metals in Space | *May* | 20 |
| HARRISON, WAYNE J., HENRY E. PAYNE, III, AND FRANK R. CARTER. The Navy's Flying Wind Tunnel | *Mar.* | 18 |
| HARTER, W. W., AND W. E. COX. One-Shot Mission Success at Minimum Cost | *Nov.* | 22 |
| HARTLINE, P. A. Operation Non-Routine: Maintenance Support Trends of Subsonic and Supersonic Transports | *June* | 38 |
| HARTVIGSEN, D. E., NORMAN R. GARNER, AND RICHARD W. VAIL, JR. Experimental Designs for Rocket Motors | *Mar.* | 12 |
| HARVEY, DOUGLAS G., AND JEROME G. MORSE. Nuclear Energy in Space—Radioisotope Auxiliary Power Systems | *Nov.* | 8 |
| HATSOPOULOS, G. N., W. B. NOTTINGHAM, AND E. N. CARABATEAS. Thermionic Conversion of Heat to Electricity | *July* | 14 |
| HENNING, PHILIP A. Directional Stability and Control With a Single Gyro | *Sept.* | 20 |
| HIBBS, A. R. Space Man vs. Space Machine | *Apr.* | 20 |
| HIMMEL, S. C., J. F. DUGAN, JR., R. W. LUIDENS, AND R. J. WEBER. A Study of Manned Nuclear-Rocket Missions to Mars | *July* | 18 |
| HINCKS, EDWARD B., AND R. W. BRAGG. Networks of Decentralized Decisions Under Central Management | *June* | 14 |
| HOELKER, RUDOLF F., AND ROBERT SILBER. Injection Schemes for Obtaining a Twenty-Four Hour Orbit | *Jan.* | 28 |
| HRUBECKY, HENRY F. Free Turbine Systems in Rotary Wing Aircraft | *Jan.* | 10 |
| HURLEY, STANLEY R., AND VAUGHN L. BEALS. The Application of Impulsive Excitation to In-Flight Vibration Testing | *Jan.* | 8 |
| HUTTON, RICHARD. Naval Attack Aviation for Limited War, 1965–1975 | *Dec.* | 10 |
| JACOBSOHN, THEODORE, AND HENRY A. MATARAZZO. Hawk Hydraulic and Electromechanical Field Maintenance Equipment | *June* | 36 |
| JAFFE, LEONARD. Use of Satellites in Commercial Communications | *Feb.* | 14 |
| JAFFEE, ROBERT I., AND MORTIMER J. LOWY. On the Development of Low-Cost, Formable, All-Metal Sandwich Panels With Corrugated Cores | *Nov.* | 14 |
| JOHNSON, WILLIAM S., JR., AND GEORGE W. MARTIN. An Aerodynamic-Influence-Coefficient Procedure | *Sept.* | 22 |
| JORDAN, WILLIS Y., JR., DONALD R. SAXTON, AND PAUL G. THOMAS. Nuclear Rocket Stages Increase Saturn's Payload Capability | *May* | 14 |
| KAZAN, ELLIOT, AND WILBUR BERGEN. V/STOL Logistic Transport: Lifting Fan Design Selection and Performance | *Apr.* | 16 |
| KELSEY, BENJAMIN S. Operations: V/STOL Worries Lie Ahead (Aerospace Technology as Seen by the Panels) | *Sept.* | 30 |
| KENNEDY, WILLIAM P. Short-Haul Air Transportation | *Dec.* | 28 |
| KLEIN, BERTRAM. Development of an All-Welded Tubular Truss Core Sandwich | *May* | 22 |
| KNOTHE, ADOLF H. Range-Safety—A Necessary Evil | *June* | 20 |
| KOERNER, TERRY W., AND JOHN J. PAULSON. Nuclear Electric Power for Space Missions | *May* | 18 |
| KRIEGER, F. J. Soviet Space Experiments and Astronautics | *July* | 8 |
| KUDROFF, MARVIN J. The First Titan Hardened Facilities | *June* | 10 |
| KURBJUN, M. C., R. F. BRISSENDEN, E. C. FOUDRIAT, AND B. B. BURTON. Pilot Control of Rendezvous | *Mar.* | 20 |
| KWIATKOWSKI, S. F., AND R. C. A'HARRAH. A New Look at V/STOL Flying Qualities | *July* | 22 |
| LAMPERT, S., AND L. J. BARBIERI. The Interdependence of Manned Spacecraft Design and Radiation Shielding | *Apr.* | 14 |
| LAUB, J. H., AND H. D. MCGINNESS. Gas-Floated Spinning Spheres | *Dec.* | 26 |
| LICHTEN, R. L., AND C. E. DAVIS. XV-3 Low-Disc-Loading V/STOL Aircraft Flight Experience | *Aug.* | 22 |
| LIEBERMAN, DAVID A., PETER G. FIELDING, AND WILLIAM H. NEFF. Control of Ground Effect Machines—Preliminary Analysis | *Dec.* | 28 |
| LIPSON, LEONARD, AND THOMAS A. LYLE. Aircraft Support Equipment at Sea | *June* | 18 |

| | Month | Page |
|---|---|---|
| Loos, J. E., J. C. Westmoreland, and J. B. Dee. A Conceptual Nuclear Propulsion System for Ground Effect Machines | *July* | 16 |
| Lowy, Mortimer J., and Robert I. Jaffee. On the Development of Low-Cost, Formable, All-Metal Sandwich Panels With Corrugated Cores | *Nov.* | 14 |
| Luidens, R. W., S. C. Himmel, J. F. Dugan, Jr., and R. J. Weber. A Study of Manned Nuclear-Rocket Missions to Mars | *July* | 18 |
| Lukasiewicz, J. Effects of Boundary Layer and Geometry on Characteristics of Perforated Walls for Transonic Wind Tunnels | *Apr.* | 22 |
| Lyle, Thomas A., and Leonard Lipson. Aircraft Support Equipment at Sea | *June* | 18 |
| MacAllister, Leonard C., and Anthony M. Smith. Data Capsule Ejection Through a Re-Entry Body Wake | *May* | 8 |
| Manring, Edward R. Optical Tracers for Atmosphere Soundings | *Sept.* | 8 |
| Mark, Herman, and Simon Ostrach. The Inflated Satellite: Characteristics in Sunlight and Darkness | *Apr.* | 10 |
| Martin, George W., and William S. Johnson, Jr. An Aerodynamic-Influence-Coefficient Procedure | *Sept.* | 22 |
| Mason, James D. Temperature Sensitivity in Germanium Transistors (Adventures in Engineering) | *Oct.* | 27 |
| Matarazzo, Henry A., and Theodore Jacobsohn. Hawk Hydraulic and Electromechanical Field Maintenance Equipment | *June* | 36 |
| McGinness, H. D., and J. H. Laub. Gas-Floated Spinning Spheres | *Dec.* | 26 |
| Mellinger, George R. The X-15 | *Aug.* | 12 |
| Mello, J. F., and K. R. Sivier. Supersonic Induced Rolling-Moment Characteristics of Cruciform Wing Body Configurations at High Angles of Attack | *July* | 20 |
| Menard, Joseph A., and Robert H. Smith. Supercircular Entry and Recovery With Maneuverable Manned Vehicles | *Oct.* | 12 |
| Mistretta, Andrew L., and Frank M. Anthony. Leading-Edge Design With Brittle Materials | *Nov.* | 20 |
| Miyashita, Jun-ichi, and Shigenori Ando. Comments on Aerodynamic Drag of Ground Effect Machines | *Nov.* | 24 |
| Morgenstern, Oskar. A Political Economist Views the Navy/Industry Look at the Future | *Dec.* | 22 |
| Morse, Jerome G., and Douglas G. Harvey. Nuclear Energy in Space—Radioisotope Auxiliary Power Systems | *Nov.* | 8 |
| Morse, Richard S. Space and Democracy | *June* | 24 |
| Multhopp, Hans. Design of Hypersonic Aircraft | *Feb.* | 8 |
| Neff, William H., David A. Lieberman, and Peter G. Fielding. Control of Ground Effect Machines—Preliminary Analysis | *Dec.* | 28 |
| Nelson, P. W., J. J. Stilwell, and W. R. Porter. Hydrofoils at the Crossroads | *Mar.* | 10 |
| Nichols, Mark R. Supersonic Transport Propulsion Requirements | *Sept.* | 12 |
| Nicolaides, John D. Project Transit—Earth and Aerospace Navigational Satellite System | *Feb.* | 20 |
| Nottingham, W. B., G. N. Hatsopoulos, and E. N. Carabateas. Thermionic Conversion of Heat to Electricity | *July* | 14 |
| Oder, Col. Frederic, and Ronald Smelt. Some Experimental Results From the Agena Satellite Program | *Feb.* | 10 |
| Ohlinger, Lee A. For the Air Force—A New Scientific Management Technique | *Nov.* | 10 |
| O'Keefe, John A., and Barbara E. Shute. Tektites and Natural Satellites of the Earth | *July* | 26 |
| Ostrach, Simon, and Herman Mark. The Inflated Satellite: Characteristics in Sunlight and Darkness | *Apr.* | 10 |
| Owens, William R. Support: Problems in Concurrent Development and Production (Aerospace Technology as Seen by the Panels) | *Nov.* | 6 |
| Padlog, Joseph, and Ivan Rattinger. Design Implications of Creep in Pressurized Cylindrical Shells | *Mar.* | 26 |
| Pappas, C. E. Vehicle Design: Problems Surveyed (Aerospace Technology as Seen by the Panels) | *Nov.* | 7 |
| Paul, Erwin W. The Hodograph and Ballistic Missile Trajectory Problems | *Feb.* | 24 |
| Paulson, John J., and Terry W. Koerner. Nuclear Electric Power for Space Missions | *May* | 18 |
| Payne, Henry E., III, Frank R. Carter, and Wayne J. Harrison. The Navy's Flying Wind Tunnel | *Mar.* | 18 |
| Perreault, W. J. Hawk Missile Electronic Repair Shops | *June* | 16 |
| Peske, Arnold, and George Swanlund. Control Considerations for a Lunar Soft Landing | *Feb.* | 26 |
| Petersen, Robert E., and Axel O. Bergholm. Effect of Forming and Welding on Stainless Steel Columns | *Apr.* | 26 |
| Pfenninger, W., J. W. Connors, and C. B. Smith. Propulsion Systems for Laminar Flow Aircraft | *Aug.* | 16 |
| Pickerd, John C. Thrust Reversers for Jet Aircraft—Selection and Design | *Jan.* | 30 |
| Porter, W. R., J. J. Stilwell, and P. W. Nelson. Hydrofoils at the Crossroads | *Mar.* | 10 |
| Probstein, Ronald F. Recent Soviet Advances in Inviscid Hypersonic Aerodynamics | *July* | 10 |
| Rattinger, Ivan, and Joseph Padlog. Design Implications of Creep in Pressurized Cylindrical Shells | *Mar.* | 26 |
| Reichelderfer, F. W. Meteorological Satellite Systems in Weather Research and Services | *Mar.* | 22 |
| Reitz, David. Cosmic Rays, Nuclear Reactors, and Manned Space Systems | *Apr.* | 28 |
| Renfro, J. B. The Mini-Recorder System | *June* | 32 |
| Rodert, Lewis A. Management: Relating Industrial Research to Company Goals (Aerospace Technology as Seen by the Panels) | *Oct.* | 26 |
| Rodert, Lewis A. Whither Aerospace Industry Research Management? | *Mar.* | 24 |
| Rolan, Gilbert. Support: Lunar Support Equipment—The Time Is Now (Aerospace Technology as Seen by the Panels) | *Dec.* | 8 |
| Sandretto, Peter C. Communication: Will the U.S. Be First in Space? (Aerospace Technology as Seen by the Panels) | *Sept.* | 29 |
| Saxton, Donald R., Willis Y. Jordan, Jr., and Paul G. Thomas. Nuclear Rocket Stages Increase Saturn's Payload Capability | *May* | 14 |
| Shanley, F. R. Tensile Instability (Necking) of Ductile Materials | *Dec.* | 30 |
| Shute, Barbara, and John A. O'Keefe. Tektites and Natural Satellites of the Earth | *July* | 26 |

| | Month | Page |
|---|---|---|
| SILBER, ROBERT, AND RUDOLF F. HOELKER. Injection Schemes for Obtaining a Twenty-Four Hour Orbit | *Jan.* | 28 |
| SIVIER, K. R., AND J. F. MELLO. Supersonic Induced Rolling-Moment Characteristics of Cruciform Wing Body Configuration at High Angles of Attack | *July* | 20 |
| SMELT, RONALD, AND COL. FREDERIC ODER. Some Experimental Results From the Agena Satellite Program | *Feb.* | 10 |
| SMITH, A. M. O., AND DARWIN W. CLUTTER. Flow Visualization by Electrolysis of Water | *Jan.* | 24 |
| SMITH, ANTHONY M., AND LEONARD C. MACALLISTER. Data Capsule Ejection Through a Re-Entry Body Wake | *May* | 8 |
| SMITH, C. B., J. W. CONNORS, AND W. PFENNINGER. Propulsion Systems for Laminar Flow Aircraft | *Aug.* | 16 |
| SMITH, J. W., AND W. W. VAUGHAN. High-Altitude Wind Observations Above Cape Canaveral | *Oct.* | 16 |
| SMITH, ROBERT H., AND JOSEPH A. MENARD. Supercircular Entry and Recovery With Maneuverable Manned Vehicles | *Oct.* | 12 |
| SMITH, WILLIAM E., AND ROGER C. WEATHERSTON. A New Type of Thermal Radiator for Space Vehicles | *Jan.* | 16 |
| STALZER, C. E., AND J. E. DRAIM, LT. COMDRS. Vertical Floating Launch of Rocket Vehicles | *June* | 12 |
| STANTON JONES, R. Hovercraft—Some Design Problems | *Feb.* | 16 |
| STILWELL, J. J., P. W. NELSON, AND W. R. PORTER. Hydrofoils at the Crossroads | *Mar.* | 10 |
| STORMER, W. C. Compatibility of Freon 114 Used in Mercury Support Equipment With Various Hose Materials | *June* | 28 |
| STRAND, T., AND C. W. FRICK. Recoverable Air-Breathing Boosters—Analysis of Their Potentialities | *Feb.* | 22 |
| STUART, WILLIAM H. Satellite Attitude Stabilization by Means of Flywheels | *Sept.* | 10 |
| SULLIVAN, PHILLIP J., AND MELL D. CASSIDY. Supersonic Ejectable-Nose Escape Capsule | *Mar.* | 14 |
| SWANLUND, GEORGE, AND ARNOLD PESKE. Control Considerations for a Lunar Soft Landing | *Feb.* | 26 |
| THAYER, W. PAUL. The Missile Threat—Future Anti-Air Warfare | *Dec.* | 16 |
| THOMAS, PAUL G., WILLIS Y. JORDAN, JR., AND DONALD R. SAXTON. Nuclear Rocket Stages Increase Saturn's Payload Capability | *May* | 14 |
| TING, LU. Approximating Technique for Variational Problems | *Jan.* | 32 |
| TOPPING, A. D. An Introduction to Biaxial Stress Problems in Fabric Structures | *Apr.* | 18 |
| TRELLA, MASSIMO, AND ROBERTO VAGLIO-LAURIN. A Study of Flow Fields About Some Typical Blunt-Nosed Slender Bodies | *Aug.* | 20 |
| TRILLING, LEON. Soviet Aeronautical Scientists: How They Work and Where They Publish | *July* | 12 |
| UNGAR, ERIC E. Response of Plates to Moving Shocks | *Mar.* | 16 |
| VAGLIO-LAURIN, ROBERTO, AND MASSIMO TRELLA. A Study of Flow Fields About Some Typical Blunt-Nosed Slender Bodies | *Aug.* | 20 |
| VAIL, RICHARD W., JR., NORMAN R. GARNER, AND D. E. HARTVIGSEN. Experimental Designs for Rocket Motors | *Mar.* | 12 |
| VALLURI, SITARAM RAO. A Unified Engineering Theory of High Stress Level Fatigue | *Oct.* | 18 |
| VAUGHAN, W. W., AND J. W. SMITH. High-Altitude Wind Observations Above Cape Canaveral | *Oct.* | 16 |
| WEATHERSTON, ROGER C., AND WILLIAM E. SMITH. A New Type of Thermal Radiator for Space Vehicles | *Jan.* | 16 |
| WEBER, R. J., S. C. HIMMEL, J. F. DUGAN, JR., AND R. W. LUIDENS. A Study of Manned Nuclear-Rocket Missions to Mars | *July* | 18 |
| WEITZ, HARRY. Twenty Times Better—The Building of a Centrifuge (Adventures in Engineering) | *Dec.* | 32 |
| WESTBROOK, C. B. Flight Mechanics: Reliability—One of Today's Dominant Problems (Aerospace Technology as Seen by the Panels) | *Oct.* | 25 |
| WESTMORELAND, J. C., J. B. DEE, AND J. E. LOOS. A Conceptual Nuclear Propulsion System for Ground Effect Machines | *July* | 16 |
| WINGROVE, RODNEY C., AND ROBERT E. COATE. Piloted Simulation Studies of Re-Entry Guidance and Control at Parabolic Velocities | *Oct.* | 10 |
| WOHL, JOSEPH G. Man-Machine Dynamics of Nose-Wheel Steering | *Oct.* | 20 |
| WYCHORSKI, HENRY J. Reproduction of Aircraft Dynamic Response in Real-Time by a Digital Computer System | *May* | 10 |
| YAO, JOHN C. Thermal-Stress Analysis of Sandwich-Type Cylindrical Shells by the Cross Method | *Aug.* | 24 |
| YOLER, YUSUF A. Dyna-Soar: A Review of the Technology | *Aug.* | 8 |
| YOUNG, PEARL I. Finding Rare Documents (Adventures in Engineering) | *Nov.* | 26 |
| ZIPKIN, M. A. Environmental Problems in the Design of Space Power Systems | *Aug.* | 14 |


✦ ✦ ✦


## An Authorized Binding For

## Aerospace Engineering

Arrangements have been made by the Institute of the Aerospace Sciences for members and subscribers to have their magazines bound carefully and economically. Simply write for details to:
**Publishers' Authorized Bindery Service Ltd.,** 430 West Erie St., Chicago 10, Ill.

## IAS SPECIAL PUBLICATIONS

| | Member | Nonmember |
|---|---|---|
| Aerospace Support and Operations Meeting Proceedings - 1961 (192 pp.) | $6.00 | $12.00* |
| Vehicle Systems Optimization Symposium Proceedings-1961 (168 pp.) | 5.00 | 10.00* |
| IAS/Army Aviation Meeting Proceedings - 1961 (68 pp.) | 2.50 | 5.00* |
| Guidance of Aerospace Vehicles Proceedings-1960 (252 pp.) | 5.00 | 10.00* |
| National Midwestern Meeting on Air Logistics Proceedings - 1960 (116 pp.) | 5.00 | 10.00* |
| Weapons Systems Management - National Midwestern Meeting Proceedings - 1957 (60 pp.) | 1.50 | 2.50* |
| National Symposium on Hypervelocity Techniques Proceedings - 1960 (176 pp.) | 5.00 | 10.00* |
| Recovery of Space Vehicles Symposium Proceedings - 1960 (104 pp.) | 4.00 | 8.00* |
| National Specialists Meeting on Dynamics & Aeroelasticity Proceedings - 1958 (136 pp.) | 3.50 | 6.00* |
| 1961 National Telemetering Conference Report | 3.50 | 5.50* |
| 1960 National Telemetering Conference Report | 4.50 | 6.50* |
| 1959 National Telemetering Conference Report | 3.00 | 4.00* |
| Frontiers of Science & Engineering Symposium Proceedings - 1959 (132 pp.) | 5.00 | 10.00* |
| Fourth Turbine-Powered Air Transportation Meeting Proceedings - 1959 | 2.00 | 4.00* |
| Second Turbine-Powered Air Transportation Meeting Proceedings - 1955 | 3.50 | 6.00* |
| 7th Anglo-American Aeronautical Conference Proceedings - 1959 | 20.00 | 25.00* |
| 5th International Aeronautical Conference Proceedings - 1955 | 15.00 | 20.00* |
| 2nd International Aeronautical Conference Proceedings - 1949 | 5.00 | 5.00* |
| National Naval Aviation Meeting Proceedings - 1957 (124 pp.) | 3.00 | 5.00* |
| Index to Books on Selected Technical Subjects in the IAS Library (up to 1950), unbound | 2.00 | 2.00* |
| Aerospace Engineering Index - 1958 | 10.00 | 15.00* |
| Aeronautical Engineering Index - 1956 and 1957 (each) | 10.00 | 15.00* |
| Aeronautical Engineering Index - 1947 through 1955 (each) | 3.00 | 5.00* |

* Add $1.00 for orders outside the U.S.A.

*These may be obtained by writing to:* Special Publications Dept., IAS, 2 E. 64th St., N.Y. 21, N.Y.

✦ ✦ ✦

# IAS/ARS JOINT MEETING

## LOS ANGELES, JUNE 13–16, 1961*

61-88 -1782 Trends in Air Cargo—H. Carter & J. Jackovich
61-89 -1783 Factors Underlying the Future Domestic Market for Air Cargo Service—G. Busch & K. Mayer
61-91 -1785 Air Trailer Transportation—W. Ligon
61-92 -1786 Economics of Air Eligibility—L. Regan & G. Harris
61-95 -1789 Maximizing Reliability for One-Shot Space Missions—S. Morrison
61-96 -1790 One-Shot Mission Success for Minimum Cost—W. Cox & W. Harter
61-104-1798 Short Haul Air Transportation—W. Kennedy
61-105-1799 Aerodynamic Characteristics of Subsonic V/STOL Transport Airplanes—M. Kelly & C. Holzhauser
61-106-1800 Application of Laminar Flow Control to Transport Aircraft—W. Gasich
61-115-1809 Prediction of Optimum Approach & Landing Techniques-Manned Reentry Gliders—L. Gaines & T. Surber
61-116-1810 Second Order Theory of Entry Mechanics into a Planetary Atmosphere—W. Loh
61-118-1812 Instrument Flight Simulator Study of VTOL Controllability-Control Power Relationship—J. Patierno & J. Isca
61-119-1813 Design Characteristics of a Lifting Fan V/STOL Logistic Transport—E. Kazan & W. Bergen
61-120-1814 Influence of Two-Dimensional Stream Shear on Airfoil Maximum Lift—R. Vidal
61-123-1817 Age Concept of Management for Ground Environment Area—S. Tremaine
61-124-1818 Universal Program-Comparator Checkout Equipment & Logistical Considerations—E. Metsker & M. Beeson
61-125-1819 Role of Operational Analyses in Planning Effective Missile Ground System—S. Firstman
61-126-1820 Compiling of Automatic Test Equipment Programs—E. Quinn and C. Chipps
61-129-1823 Study of Solid-Fuel Ramjet Applications—P. Munter
61-134-1828 Description of Weapons Assignment Research Model (WARM)—R. Totschek
61-135-1829 General Purpose Simulator for Airborne Computers—E. Carter
61-143-1837 Design Alternatives for In-Flight Maintenance—R. Demaree
61-144-1838 Human Engineering Principles of Design for In-Space Maintenance—L. Pigg
61-146-1840 Predicting Human Reliability-Implications for Operations & Maintenance in Space—R. Kaufman, T. Oehrlein, & M. Kaufmann
61-147-1841 Some Experiments of Human Maintenance Behavior—M. Grodsky
61-149-1843 Unified Engineering Theory of High Stress Level Fatigue—S. Valluri
61-150-1844 Structural Aspects of Low Drag Suction Airfoils—J. Wieder & W. Pfenninger
61-151-1845 Leading Edge Design with Brittle Materials—F. Anthony & A. Mistretta
61-158-1852 Mercury Animal Program—J. Henry and J. Mosely
61-162-1856 The Mini-Recorder System—J. Renfro
61-183-1877 Directive Non-Oriented Reflectors as Passive Satellites in Long Distance Communications—Y. Stahler & A. Johnson
61-190-1884 The Magnetic Particle Clutch–A Versatile Control Element for Rocket Systems—B. Grau & B. Chubb
61-194-1888 X-15 Flight Simulation Program—N. Cooper
61-195-1889 Piloted Simulation Studies of Re-entry Guidance & Control at Parabolic Velocities—R. Wingrove & R. Coate
61-196-1890 The Simulator as a Human Factors Research Tool for Manned Space Flight—G. Simon
61-210-1904 Flow Past Slender Blunt Bodies–Review & Extension—R. Capieux & L. Karchmar

*See pp. 64 and 80 for other IAS publications available. **IAS/ARS Member price, 50c each. Nonmember price, $1.00 each.**

*Order by number from:* Special Publications Dept., IAS, 2 E. 64th St., New York 21, N.Y.

# Personnel Opportunities

*This section is for the use of individual members of the Institute seeking new connections and eligible organizations offering employment to specialists in the aerospace industry. Any member or eligible organization may have requirements listed without charge by writing to the Secretary of the Institute.*

**The number preceding the notice represents the Box Number of the Institute of the Aerospace Sciences to which inquiries should be addressed.**

## Wanted

**Missile Propulsion Preliminary Design**—Applying advanced propulsion concepts, this engineer will prepare systems analyses and trade-off studies on new concepts in missile propulsion design. He will prepare technical proposals on rocket engine hardware problems including solid propellant nozzle design and motor insulation. A minimum of 6 years' related experience required plus M.S.M.E. **Controls Analysis**—Responsible for the analysis and evaluation of aircraft-missile-electromechanical, servocontrol systems. Capability of defining stability performance and dynamics of physical systems in terms of differential equations necessary. Analysis techniques will include use of La-Place transforms, Nyquist stability criteria, and Bode plots. Related degrees plus several years' experience. **Operations Research Specialist**—Apply theory of operations research to selection and optimization of military weapons systems. Background in game theory and information theory desirable. Man will work on advanced projects involving the entire spectrum of environments from space to undersea. **Magnetohydrodynamics Specialist**—To plan and perform research in the field of magnetohydrodynamics, power generation, and plasma as related to nuclear power and space power systems. M.S. in physics or engineering plus minimum of 5 years' experience. **Plasma Engine Specialist**—To plan and perform basic research in the fields of plasma and ion engines, magnetohydrodynamics, and power generation as related to nuclear power and space power systems. Ph.D. in physics or engineering plus minimum of 5 years' experience. **Gasdynamics Engineer**—To undertake studies in gasdynamics, heat transfer, supersonic aerodynamics, and fluid flow for support of rocket nozzle programs, systems for thrust vector controls, hot gas steering systems, auxiliary power units, and similar advanced engineering programs. Advanced degree plus 3 years' experience. Write fully to R. J. Theibert, Employment Manager, Tapco Group, Thompson Ramo Wooldridge, Inc., 23555 Euclid Ave., Cleveland 17, Ohio.

**Aircraft Stability and Control Engineer**—Analysis and evaluation of stability and control characteristics of naval aircraft. Planning, monitoring, and reviewing results of research and development investigations, both wind tunnel and flight test, of specific aircraft configurations. Administration of flying qualities design and demonstration specifications, as well as administration of research contracts in stability and control. Requires experience in stability and control analysis. Positions available at grades GS-11, $7,560 per annum, through GS-13, $10,635, in accordance with qualifications. Employment will be effected under Civil Service regulations. Apply to Bureau of Naval Weapons (DCP-321), Department of the Navy, Washington 25, D.C.

## Available

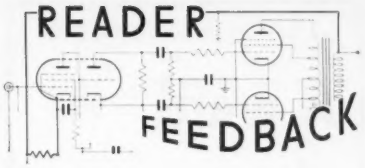
**142. Aeronautical Engineer**—M.S. in A.E. Fifteen years' experience including structural design, stress analysis, structural loads and criteria, wind-tunnel testing, stability and control (including both aerodynamics and airplane dynamics). Familiar with the use of analog and digital computers, Forstran coding, and automatic control systems. Experience covers high-performance military aircraft and commercial aircraft. Present position: project aerosystems engineer. A challenging engineering or management position in a small organization is desired. Résumé on request.

**141. Research Engineer**—Age 39; former head of university engineering research organization, now VTOL project aerodynamicist for aircraft manufacturer, desires increased research managerial responsibility. Fifteen years' industrial and academic experience, as university aeronautical engineering option head, research project engineer, and project director for sponsored STOL and VTOL analytical wind-tunnel and flight research programs. Complete résumé on request.

**140. Airline Executive**—A.E. and M.E. degrees. Member IAS. Sixteen years' extensive experience in management, operational and technical fields, including proved capability in planning and coordinating aircraft integration programs, performance and economic evaluation of proposed aircraft, and development of airplane operating procedures. Experienced in airplane contract negotiations, development of corporate planning premises, and personnel and budget administration. Particularly interested in program or project planning. Wish opportunity to explore other possibilities with you. Résumé furnished on request.

**139. Director of Engineering and Maintenance**—Twenty-one years of progressively increasing technical and administrative responsibility for the design, analysis, procurement, operation, and maintenance of commercial transport and military aircraft in domestic and international service. B.S.M.E., aeronautical major. Colonel, USAF Reserve. Age 43. Résumé upon request.

***Notices of all change of address should be sent to the Circulation Department, Institute of the Aerospace Sciences, Inc., 2 East 64th Street, New York 21, N.Y., at least 30 days prior to change of address.***




Comments from readers expressing opinions about the editorial coverage, format, etc., of *Aerospace Engineering*, or offering suggestions for general improvement of this IAS publication, are welcomed by the Editors. To simplify forwarding of such data in capsule form, and its retention for ready review, it is requested that readers tear out and mail this questionnaire, completed to the degree desired, to **Reader Feedback, *Aerospace Engineering*, 2 East 64th Street, New York 21, N.Y.** All will receive serious consideration, though none can be acknowledged. (*Reader Feedback* is intended as a rapid and convenient means of communication; the Editors invite and will welcome full-fledged *Letters to the Editor.*)

1. Which article(s) published in this or any recent issue of *Aerospace Engineering* was (were) of most value to you professionally? (Name of *senior author* and *month* are required; title need not be listed.)

(a) _____

(b) _____

(c) _____

2. Do you notice a change in emphasis regarding your particular branch of engineering? What is it? What particular articles do you think would interest the greatest number of your associates in engineering? (*Please answer as completely as possible.*)

_____

_____

_____

3. Do you prefer articles of a review nature or those dealing with a specific problem or achievement within a single discipline?

_____

**Name** _____ _____
(*Optional*) (IAS grade)

_____ _____
(Position) (Company)

_____
(Home or business address)

**Additional Comments** _____

_____

_____

_____

# A word about our Advertisers

The many companies whose advertising appears in this issue are interested in you and your work. They are anxious to let you know what they are doing to help you solve research and design problems in missile, rocket, air, and spacecraft projects.

AEROSPACE ENGINEERING's advertising pages keep you posted on new and improved materials, components, services, and supplies useful to your professional work.

To request more information on any product or service advertised, may we suggest you write to the *advertiser* directly, at no obligation to you. It would be greatly appreciated if you would mention that you saw the ad in AEROSPACE ENGINEERING.

AEROSPACE ENGINEERING
Established 1934
2 E. 64th St., New York 21, N. Y.

# Index to Advertisers

AiResearch Mfg. Divs., The Garrett Corp. ..... 1
*J. Walter Thompson Co.*

American Bosch Arma Corp., Arma Div. ..... inside front cover
*Doyle, Kitchen & McCormick, Inc.*

American Machine & Foundry Co., Government Products Group ..... 37
*Cunningham & Walsh, Inc.*

Bell Helicopter Company ..... 55
*Rogers & Smith Advertising Agents, Inc.*

The Boeing Company ..... 2
*Fletcher Richards, Calkins & Holden, Inc.*

Components Div., International Telephone & Telegraph Corp. ..... 33
*Gaynor & Ducas, Inc.*

Defense Electronic Products, Radio Corporation of America ..... 6,7
*Al Paul Lefton Co., Inc.*

Douglas Aircraft Co., Inc. ..... outside back cover
*J. Walter Thompson Co.*

Eastman Kodak Co. ..... 59
*The Rumrill Co., Inc.*

The Garrett Corp., AiResearch Mfg. Divs. ..... 1
*J. Walter Thompson Co.*

The B. F. Goodrich Co., Aviation Products ..... 44, 45
*The Griswold-Eshleman Company*

Government Products Group, American Machine & Foundry Co. ..... 37
*Cunningham & Walsh, Inc.*

Harrison Mfg. Co. ..... 5
*Robert Edward Lee Agency*

International Aerospace Abstracts ..... 57

International Telephone & Telegraph Corp., Components Div. ..... 33
*Gaynor & Ducas, Inc.*

Lincoln Laboratory, Massachusetts Institute of Technology ..... 53
*Randolph Associates*

MPB, Inc., Split Ballbearing Div. ..... 41
*Watson-Manning Advertising*

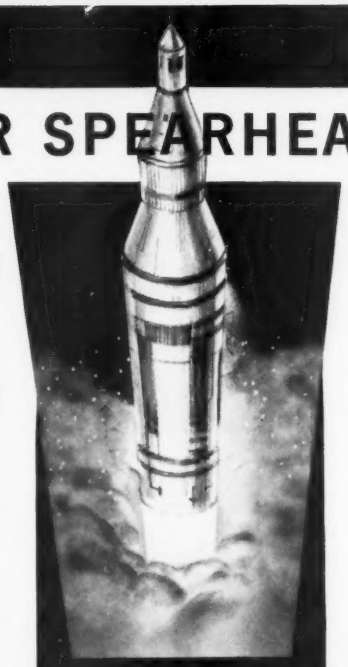
Radio Corporation of America, Defense Electronic Products ..... 6,7
*Al Paul Lefton Co., Inc.*

Sperry ..... 49
*Reach, McClinton & Co.*

Split Ballbearing Div., MPB, Inc. ..... 41
*Watson-Manning Advertising*

Wyman-Gordon Co. ..... inside back cover
*Davis Advertising, Inc.*

# FORGING OUR SPEARHEADS IN SPACE



1 Titanium motor case parts totalling 2010 lbs.
2 ICBM heat sink cone; Copper, 1876 lbs.
3 Ported motor closure; 74 lbs., Aluminum.
4 Magnesium turbopump ring gear; 35 lbs.
5 Sustainer ring; 208 lbs., alloy steel.
6 Aluminum airframe ring splice; 53 lbs.
7 Missile blast cone; 237 lbs., carbon steel.
8 Stainless steel injector plate; 155 lbs.
9 Payload container; 10 lbs., Beryllium.
10 Super-strength steel head; 725 lbs.
11 Missile fin spar; 65 lbs., Aluminum.
12 Thrust cone; 613 lbs., alloy steel.
13 Power system part; 1300 lbs., Columbium.
14 Titanium igniter nozzle; 122 lbs.
15 Pressure bottle half; Titanium, 173 lbs.
16 Astroloy turbopump wheel; 170 lbs.
17 Heat shield backup; 134 lbs., Magnesium.
18 Airframe wind arm; 129 lbs., Aluminum.
19 Super-strength steel, 3100-lb. head.
20 Alloy-steel missile bulkhead; 130 lbs.
21 Tungsten nozzle throat insert; 115 lbs.
22 Aluminum sustainer thrust cone; 110 lbs.
23 Aft closure; 1600 lbs., super-strength steel.
24 Airframe rib spar; 95 lbs., Titanium.
25 Motor-case Titanium closure; 590 lbs.
26 Missile bulkhead; Aluminum, 89 lbs.
27 Beryllium guidance carrier ring; 23 lbs.
28 Booster turbowheel; Rene 41, 948 lbs.
29 Rocket spur gear; T8 lbs., Magnesium.
30 Magnesium satellite canister; 229 lbs.
31 IRBM Jetevator ring; 45 lbs., Molybdenum.
32 Missile motor Copper blast cone; 88 lbs.
33 IRBM spacer ring; 78 lbs., Tungsten.
34 Aluminum longeron for ICBM; 36 lbs.
35 Launching shoe; 26 lbs., alloy steel.
36 Columbium power system part; 1100 lbs.
37 Tungsten thrust-chamber throat; 32 lbs.
38 Glide vehicle component; Rene 41, 3 lbs.
39 Beryllium guidance main shaft; 9 lbs.
40 Launch vehicle domes; capability to 160".

To call the roll of America's space efforts—in missiles, satellites, launch vehicles and spacecraft—is virtually to name the projects which rely on Wyman-Gordon forgings.

Specialization has made it so. For this is the one source whose pioneering in the sophisticated metal-forming requirements of flight dates from the dawn of our air age.

Thus Wyman-Gordon brings to today's space challenges a record of hot-working achievement and experience unduplicated in both environments.

This background considerably extends the scope of Wyman-Gordon forging services. Here, broad-spectrum capabilities in engineering, metallurgy and basic research are teamed with space-oriented facilities to forge vital components in all areas—payload, guidance, airframe, propulsion, auxiliary power and ground support.

Consultation can indicate how ultimate performance of your project's critical-mission hardware may benefit from Wyman-Gordon breakthroughs in forging exotic and refractory materials to new design parameters.

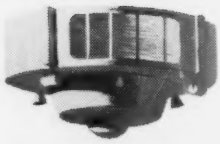
**WYMAN-GORDON**

**FORGINGS**

*of Aluminum Magnesium Steel Titanium . . . and Beryllium Molybdenum Columbium and other uncommon materials*

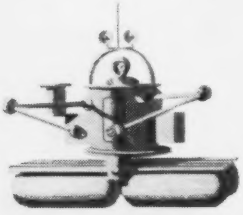
HARVEY ILLINOIS WORCESTER MASSACHUSETTS GRAFTON MASSACHUSETTS
DETROIT MICHIGAN LOS ANGELES CALIFORNIA PALO ALTO CALIFORNIA FORT WORTH TEXAS

GR7

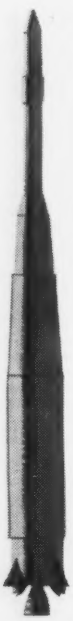


**Lunar VTOL Vehicle.** A rocket-propelled craft designed to collect lunar ore specimens.

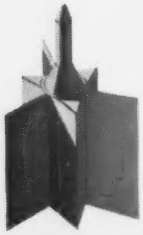
**Nuclear Space Ship.** A Douglas design for a space ship with crew quarters and control rooms in the nose, nuclear reactor in the rear.



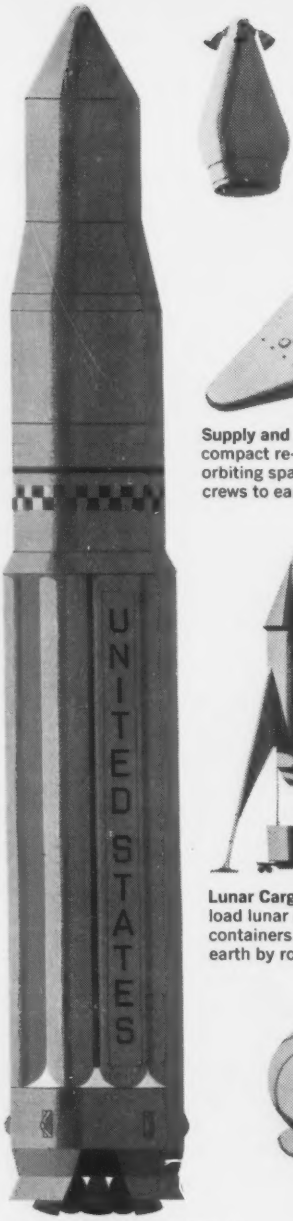
**Lunar Service Vehicle.** Travels like a "swamp buggy" on inflated rollers. Mechanical arms provided to handle outside chores.



**Douglas Thor.** Designed as a military IRBM, this dependable missile is the workhorse of the Space Age.



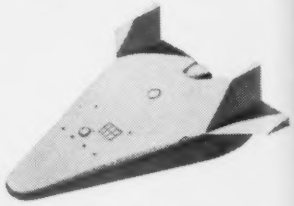
**Nuclear Space Ship.** A future, medium-thrust, nuclear-electric space ship for one-year interplanetary round trips (Martian and Venusian).



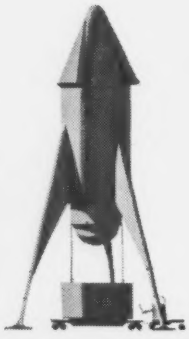

**Saturn.** First U.S. vehicle designed to put tons of payload into orbit . . . or onto the moon. Douglas-built second stage is as tall as a 4-story building.



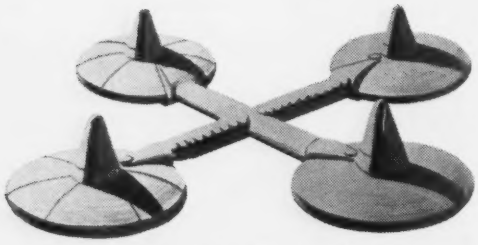
**Nuclear Space Ship.** An unconventional design by Douglas with living quarters around the ring at the bottom. On landing, it would ease down, ring first.



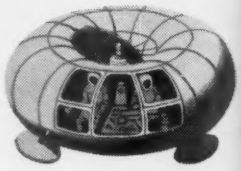
**Supply and Escape Vehicle.** A compact re-entry vehicle to supply orbiting space stations or to return crews to earth.



**Lunar Cargo Handlers.** Would load lunar ore samples into containers to be towed back to earth by rockets.



**Space Observatory.** Sections of this Douglas-designed space station would be sent into space in rockets and be joined together in orbit.



**Lunarmobile.** Donut-shaped exploration vehicle to use rocket power in space and tractor treads on the moon's surface.

# Eleven ways to outwit the law of gravity

When the Space Age dawned, Douglas was ready with specific proposals for space equipment either completed or in advanced stages of development. (Some appear above.)

These Douglas proposals were based on *realistic* estimates of the capabilities of men and materials. They are the valued dividends of the company's considerable experience, gained from the design and production of 30,000 missiles and rockets. These include the Douglas *Thor*, an IRBM which has been totally successful in 89.5% of its tactical and space firings over the past two years.

Today, Douglas looks ahead to other exciting challenges from its firm position of leadership in the conquest of Space.

DOUGLAS

MISSILE AND SPACE SYSTEMS • MILITARY AIRCRAFT • DC
JETLINERS • RESEARCH AND DEVELOPMENT PROJECTS
GROUND SUPPORT EQUIPMENT • AIRCOMB® • ASW DEVICE